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(54) Title: PROCEDURES AND EQUIPMENT FOR PROFILING AND JOINTING OF PIPES

(57) Abstract

Methods and apparatus for shaping pipes, tubes, liners, or casing at downhole locations in wells. Use is made of rollers bearing radially outwards against the inside wall of the pipe (etc.), the rollers being rolled around the pipe to cause outward plastic deformation which expands and shapes the pipe to a desired profile. Where one pipe is inside another, the two pipes can be joined without separate components (except optional seals). Landing nipples and liner hangers can be formed in situ. Valves can be deployed to a selected downhole location and there sealed to the casing or liner without separate packers. Casing can be deployed downhole in reduced-diameter lengths and then expanded to case a well without requiring larger diameter bores and casing further uphole. The invention enables simplified downhole working, and enables a well to be drilled and produced with the minimum downhole bore throughout its depth, obviating the need for large bores. When expanding lengths of casing, the casing does not need to be anchored or made pressure-tight. The profiling/expansion tools of the invention can be deployed downhole on coiled tubing, and operated without high tensile loads on the coiled tubing.

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1 **PROCEDURES AND EQUIPMENT FOR**
2 **PROFILING AND JOINTING OF PIPES.**

3 This invention relates to procedures and equipment for
4 profiling and jointing of pipes, and relates more
5 particularly but not exclusively to methods and
6 apparatus for the shaping and/or expansion and/or
7 conjoining of tubular casings in wells.

8 In the hydrocarbon exploration and production industry
9 there is a requirement to deploy tubular casings in
10 relatively narrow-bore wells, and to expand the
11 deployed casing in situ. The casing may require to be
12 expanded throughout its length in order to line a bore
13 drilled through geological material; the casing may
14 additionally or alternatively require to be expanded at
15 one end where it overlaps and lies concentrically
16 within another length of previously deployed casing in
17 order to form a swaged joint between the two lengths of
18 casing. Proposals have been made that a slotted metal
19 tube be expanded by mechanically pulling a mandrel
20 through the tube, and that a solid-walled steel tube be
21 expanded by hydraulically pushing a part-conical
22 ceramic plunger through the tube. In both of these
23 proposals, very high longitudinal forces would be
24 exerted throughout the length of the tubing, which
25 accordingly would require to be anchored at one end.

1 Where mechanical pulling is to be employed, the pulling
2 force would require to be exerted through a drillstring
3 (in relatively large diameter wells) or through coiled
4 tubing (in relatively small diameter wells). The
5 necessary force would become harder to apply as the
6 well became more deviated (i.e. more non-vertical), and
7 in any event, coiled tubing may not tolerate high
8 longitudinal forces. Where hydraulic pushing is to be
9 employed, the required pressure may be hazardously
10 high, and in any event the downhole system would
11 require to be pressure-tight and substantially leak-
12 free. (This would preclude the use of a hydraulically
13 pushed mandrel for the expansion of slotted tubes).
14 The use of a fixed-diameter mandrel or plug would make
15 it impracticable or impossible to control or to vary
16 post-deformation diameter after the start of the
17 expansion procedure.

18 It is therefore an object of the invention to provide
19 new and improved procedures and equipment for the
20 profiling or jointing of pipes or other hollow tubular
21 articles, which obviate or mitigate at least some of
22 the disadvantages of the prior art.

23 In the following specification and claims, references
24 to a "pipe" are to be taken as references to a hollow
25 tubular pipe and to other forms of hollow tubular
26 article, and references to "profiling" are to be taken
27 as comprising alteration of shape and/or dimension(s)
28 which alteration preferably takes place substantially
29 without removal of material.

30
31 According to a first aspect of the present invention
32 there is provided a profiling method for profiling a
33 pipe or other hollow tubular article, the profiling

1 method comprising the steps of applying a roller means
2 to a part of the pipe bore selected to be profiled,
3 translating the roller means across the bore in a
4 direction including a circumferential component while
5 applying a force to the roller means in a radially
6 outwards direction with respect to the longitudinal
7 axis of the pipe, and continuing such translation and
8 force application until the pipe is plastically
9 deformed substantially into the intended profile.

10 The deformation of the pipe may be accomplished by
11 radial compression of the pipe wall or by
12 circumferential stretching of the pipe wall, or by a
13 combination of such radial compression and
14 circumferential stretching.

15 Said direction may be purely circumferential, or said
16 direction may partly circumferential and partly
17 longitudinal.

18 Said roller means is preferably peripherally profiled
19 to be complementary to the profile into which the
20 selected part of the pipe bore is intended to be
21 formed.

22 The selected part of the pipe bore may be remote from
23 an open end of the pipe, and the profiling method then
24 comprises the further steps of inserting the roller
25 means into the open end of the pipe (if the roller
26 means is not already in the pipe), and transferring the
27 roller means along the pipe to the selected location.
28 Transfer of the roller means is preferably accomplished
29 by the step of actuating traction means coupled to or
30 forming part of the roller means and effective to apply
31 along-pipe traction forces to the roller means by

1 reaction against parts of the pipe bore adjacent the
2 roller means.

3 The profiling method according to the first aspect of
4 the present invention can be applied to the profiling
5 of casings and liners deployed in a well (e.g. a
6 hydrocarbon exploration or production well), and the
7 profile created by use of the method may be a liner
8 hanger, or a landing nipple, or another such downhole
9 profile of the type which previously had to be provided
10 by inserting an annular article or mechanism into the
11 well, lowering it the required depth, and there
12 anchoring it (which required either a larger diameter
13 of well for a given through diameter, or a restricted
14 through diameter for a given well diameter, together
15 with the costs and inconvenience of manufacturing and
16 installing the article or mechanism). Additionally or
17 alternatively, the profiling method according to the
18 first aspect of the present invention can be applied to
19 increasing the diameter of a complete length of pipe;
20 for example, where a well has been cased to a certain
21 depth (the casing having a substantially constant
22 diameter), the casing can be extended downwardly by
23 lowering a further length of pipe (of lesser diameter
24 such that it freely passes down the previously
25 installed casing) to a depth where the top of the
26 further length lies a short way into the lower end of
27 the previously installed casing and there expanding the
28 upper end of the further length to form a joint with
29 the lower end of the previously installed casing (e.g.
30 by using the method according to the second aspect of
31 the present invention), followed by circumferential
32 expansion of the remainder of the further length to
33 match the bore of the previously installed casing.

1 According to a second aspect of the present invention
2 there is provided a conjoining method for conjoining
3 two pipes or other hollow tubular articles, said
4 conjoining method comprising the steps of locating one
5 of the two pipes within and longitudinally overlapping
6 one of the other of the two pipes, applying roller
7 means to a part of the bore of the inner of the two
8 pipes at a location where it is intended that the two
9 pipes be conjoined, translating the roller means across
10 the bore in a direction including a circumferential
11 component while applying a radially outwardly directed
12 force to the roller means, and continuing such
13 translation and force application until the inner pipe
14 is plastically deformed into permanent contact with the
15 outer pipe and is thereby conjoined thereto.

16 Said deformation may be accomplished by radial
17 compression of the pipe wall or by circumferential
18 stretching of the pipe wall, or by a combination of
19 such radial compression and circumferential stretching.

20 Said direction may be purely circumferential, or said
21 direction may be partly circumferential and partly
22 longitudinal.

23 The location where the pipes are intended to be
24 conjoined may be remote from an accessible end of the
25 bore, and the conjoining method then comprises the
26 further steps of inserting the roller means into the
27 accessible end of the bore (if the roller means is not
28 already in the bore), and transferring the roller means
29 to the intended location. Transfer of the roller means
30 is preferably accomplished by the step of actuating
31 traction means coupled to or forming part of the roller
32 means and effective to apply along-bore traction forces

1 to the roller means by reaction against parts of the
2 pipe bore adjacent the roller means.

3 The conjoining method according to the second aspect of
4 the present invention can be applied to the mutual
5 joining of successive lengths of casing or liner
6 deployed in a well (e.g. a hydrocarbon exploration or
7 production well), such that conventional screw-threaded
8 connectors are not required.

9 According to third aspect of the present invention,
10 there is provided expansion apparatus for expanding a
11 pipe or other hollow tubular article, said expansion
12 apparatus comprising roller means constructed or
13 adapted for rolling deployment against the bore of the
14 pipe, said roller means comprising at least one set of
15 individual rollers each mounted for rotation about a
16 respective rotation axis which is generally parallel to
17 the longitudinal axis of the apparatus, the rotation
18 axes of said at least one set of rollers being
19 circumferentially distributed around the expansion
20 apparatus and each being radially offset from the
21 longitudinal axis of the expansion apparatus, the
22 expansion apparatus being selectively rotatable around
23 its longitudinal axis.

24 The rotation axes of said at least one set of rollers
25 may conform to a first regime in which each said
26 rotation axis is substantially parallel to the
27 longitudinal axis of the expansion apparatus in a
28 generally cylindrical configuration, or the rotation
29 axes of said at least one set of rollers may conform to
30 a second regime in which each said rotation axis lies
31 substantially in a respective radial plane including
32 the longitudinal axis of the expansion apparatus and

the rotation axes each converge substantially towards a common point substantially on the longitudinal axis of the expansion apparatus in a generally conical configuration, or the rotation axes of said at least one set of rollers may conform to third regime in which each said rotation axis is similarly skewed with respect to the longitudinal axis of the expansion apparatus in a generally helical configuration which may be non-convergent (cylindrical) or convergent (conical). Rollers in said first regime are particularly suited to profiling and finish expansion of pipes and other hollow tubular articles, rollers in said second regime are particularly suited to commencing expansion in, and to flaring of pipes, and other hollow tubular articles, while rollers in said third regime are suited to providing longitudinal traction in addition to such functions of the first or second regimes as are provided by other facets of the roller axes besides skew. The expansion apparatus may have only a single such set of rollers, or the expansion apparatus may have a plurality of such sets of rollers which may conform to two or more of the aforesaid regimes of roller axis alignments; in a particular example where the expansion apparatus has a set of rollers conforming to the second regime located at leading end of the exemplary expansion apparatus and another set of rollers conforming to the first regime located elsewhere on the exemplary expansion apparatus, this exemplary expansion apparatus is particularly suited to expanding complete lengths of hollow tubular casing by reason of the conically disposed leading set of rollers opening up previously unexpanded casing and the following set of cylindrically disposed rollers finish-expanding the casing to its intended final diameter; if this exemplary expansion apparatus were

1 modified by the addition of a further set of rollers
2 conforming to third regime with non-convergent axes;
3 this further set of rollers could be utilised for the
4 purpose of applying traction forces to the apparatus by
5 means of the principles described in the present
6 inventor's previously published PCT patent application
7 WO93/24728-A1, the contents of which are incorporated
8 herein by reference.

9 The rollers of said expansion apparatus may each be
10 mounted for rotation about its respective rotation axis
11 substantially without freedom of movement along its
12 respective rotation axis, or the rollers may each be
13 mounted for rotation about its respective rotation axis
14 with freedom of movement along its respective rotation
15 axis, preferably within predetermined limits of
16 movement. In the latter case (freedom of along-axis
17 movement within predetermined limits), this is
18 advantageous in the particular case of rollers
19 conforming to the afore-mentioned second regime (i.e. a
20 conical array of rollers) in that the effective maximum
21 outside diameter of the rollers depends on the position
22 of the rollers along the axis of the expansion
23 apparatus and this diameter is thereby effectively
24 variable; this allows relief of radially outwardly
25 directed forces by longitudinally retracting the
26 expansion apparatus to allow the rollers collectively
27 to move longitudinally in the convergent direction and
28 hence collectively to retract radially inwards away
29 from the bore against which they were immediately
30 previously pressing.

31 According to a fourth aspect of the present invention,
32 there is provided profiling/conjoining apparatus for
33 profiling or conjoining pipes or other hollow tubular

1 articles, said profiling/conjoining apparatus
2 comprising roller means and radial urging means
3 selectively operable to urge the roller means radially
4 outwards of a longitudinal axis of the
5 profiling/conjoining apparatus, the radial urging means
6 causing or allowing the roller means to move radially
7 inwards towards the longitudinal axis of the
8 profiling/conjoining apparatus when the radial urging
9 means is not operated, the roller means comprising a
10 plurality of individual rollers each mounted for
11 rotation about a respective rotation axis which is
12 substantially parallel to the longitudinal axis of the
13 profiling/conjoining apparatus, the rotation axes of
14 the individual rollers being circumferentially
15 distributed around the apparatus and each said rotation
16 axis being radially offset from the longitudinal axis
17 of the profiling/conjoining apparatus, the
18 profiling/conjoining apparatus being selectively
19 rotatable around its longitudinal axis to translate the
20 roller means across the bore of a pipe against which
21 the roller means is being radially urged.

22

23 The radial urging means may comprise a respective
24 piston on which each said roller is individually
25 rotatably mounted, each said piston being slidably
26 sealed in a respective radially extending bore formed
27 in a body of the profiling/conjoining apparatus, a
28 radially inner end of each said bore being in fluid
29 communication with fluid pressure supply means
30 selectively pressurisable to operate said radial urging
31 means.

32 Alternatively, the radial urging means may comprise bi-
33 conical race means upon which each said individual
34 roller rolls in use of the profiling/conjoining

1 apparatus, and separation variation means selectively
2 operable controllably to vary the longitudinal
3 separation of the two conical races of the bi-conical
4 race means whereby correspondingly to vary the radial
5 displacement of each said roller rotation axis from the
6 longitudinal axis of the profiling/conjoining
7 apparatus. The separation variation means may comprise
8 hydraulic linear motor means selectively pressurisable
9 to drive one of said two cones longitudinally towards
10 and/or away from the other said cone.

11 Embodiments of the invention will now be described by
12 way of example, with reference to the accompanying
13 drawings wherein :

14 Fig. 1 is a plan view of a first embodiment
15 of profiling tool;

16 Fig. 2 is an elevation of the profiling tool
17 of Fig. 1;

18 Fig. 3 is a sectional perspective view of the
19 profiling tool of Figs. 1 & 2, the section
20 being taken on the line III-III in Fig. 2;
21 Fig. 4 is an exploded perspective view of the
22 profiling tool of Figs. 1-4;

23 Figs. 5A, 5B, & 5C are simplified sectional
24 views of three successive stages of operation
25 of the profiling tool of Figs. 1-4;

26 Fig. 6 is a schematic diagram illustrating
27 the metallurgical principle underlying the
28 operational stage depicted in Fig. 5C;

11

1 Figs. 7A & 7B are illustrations corresponding
2 to Figs. 5A & 5B but in respect of a variant
3 of the Figs. 1-4 profiling tool having two
4 rollers instead of three;

5 Figs. 8A & 8B are illustrations corresponding
6 to Figs. 5A & 5B but in respect of a variant
7 of the Figs. 1-4 profiling tool having five
8 rollers instead of three;

9 Figs. 9A & 9B respectively illustrate
10 starting and finishing stages of a first
11 practical application of the profiling tool
12 of Figs. 1-4;

13 Figs. 10A & 10B respectively illustrate
14 starting and finishing stages of a second
15 practical application of the profiling tool
16 of Figs. 1-4;

17 Figs. 11A & 11B respectively illustrate
18 starting and finishing stages of a third
19 practical application of the profiling tool
20 of Figs. 1-4;

21 Figs. 12A & 12B respectively illustrate
22 starting and finishing stages of a fourth
23 practical application of the profiling tool
24 of Figs. 1-4;

25 Figs. 13A & 13B respectively illustrate
26 starting and finishing stages of a fifth
27 practical application of the profiling tool
28 of Figs. 1-4;

1 Figs. 14A & 14B respectively illustrate
2 starting and finishing stages of a sixth
3 practical application of the profiling tool
4 of Figs. 1-4;

5 Figs. 15A & 15B respectively illustrate
6 starting and finishing stages of a seventh
7 practical application of the profiling tool
8 of Figs. 1-4;

9 Figs. 16A & 16B respectively depict starting
10 and finishing stages of an eighth practical
11 application of the profiling tool of Figs. 1-
12 4;

13 Figs. 17A & 17B respectively depict starting
14 and finishing stages of a ninth practical
15 application of the profiling tool of Figs. 1-
16 4;

17 Fig. 18 schematically depicts a tenth
18 practical application of the profiling tool
19 of Figs. 1-4;

20 Fig. 19 schematically depicts an eleventh
21 practical application of the profiling tool
22 of Figs. 1-4;

23 Fig. 20 is a longitudinal elevation of a
24 first embodiment of expansion tool in
25 accordance with the present invention;

26 Fig. 21 is a longitudinal elevation, to an
27 enlarged scale, of part of the expansion tool
28 of Fig. 20;

1 Fig. 21A is an exploded view of the tool part
2 illustrated in Fig. 20;

3 Fig. 22 is a longitudinal section of the tool
4 part illustrated in Fig. 20;

5 Fig. 23 is a longitudinal section of the
6 expansion tool illustrated in Fig. 21;

7 Fig. 24 is an exploded view of part of the
8 expansion tool illustrated in Fig. 20;

9 Fig. 25 is a longitudinal section of an
10 alternative form of the tool part illustrated
11 in Fig. 21;

12 Fig. 26 is a longitudinal section of a
13 technical variant of the tool part
14 illustrated in Fig. 21;

15 Fig. 27 is a longitudinal elevation of a
16 second embodiment of expansion tool in
17 accordance with the present invention;

18 Figs. 28A, 28B, & 28C are respectively a
19 longitudinal section, a longitudinal
20 elevation, and a simplified end view of a
21 third embodiment of expansion tool in
22 accordance with the present invention;

23 Figs. 29A & 29B are longitudinal sections of
24 a fourth embodiment of expansion tool in
25 accordance with the present invention,
26 respectively in expanded and contracted
27 configurations; and

1 Fig. 30 is a longitudinal section of a fifth
2 embodiment of expansion tool in accordance
3 with the present invention.

4 Referring first to Figs. 1 & 2, these depict a three-
5 roller profiling tool 100 in accordance with the
6 present invention. The tool 100 has a body 102 which
7 is hollow and generally tubular, with conventional
8 screw-threaded end connectors 104 & 106 for connection
9 to other components (not shown) of a downhole assembly.
10 The end connectors 104 & 106 are of reduced diameter
11 (compared to the outside diameter of the longitudinally
12 central body part 108 of the tool 100), and together
13 with three longitudinal flutes 110 on the central body
14 part 108, allow the passage of fluids along the outside
15 of the tool 100. The central body part 108 has three
16 lands 112 defined between the three flutes 110, each
17 land 112 being formed with a respective recess 114 to
18 hold a respective roller 116 (see also Figs. 3 & 4).
19 Each of the recesses 114 has parallel sides and extends
20 radially from the radially perforated tubular core 115
21 of the tool 100 to the exterior of the respective land
22 112. Each of the mutually identical rollers 116 is
23 near-cylindrical and slightly barrelled (i.e. of slight-
24 ly greater diameter in its longitudinally central
25 region than at either longitudinal end, with a
26 generally convex profile having a discontinuity-free
27 transition between greatest and least diameters). Each
28 of the rollers 116 is mounted by means of a bearing 118
29 at each end of the respective roller for rotation about
30 a respective rotation axis which is parallel to the
31 longitudinal axis of the tool 100 and radially offset
32 therefrom at 120-degree mutual circumferential
33 separations around the central part 108. The bearings
34 118 are formed as integral end members of radially

1 slidable pistons 120, one piston 120 being slidably
2 sealed within each radially extending recess 114. The
3 inner end of each piston 120 is exposed to the pressure
4 of fluid within the hollow core of the tool 100 by way
5 of the radial perforations in the tubular core 115; in
6 use of the tool 100, this fluid pressure will be the
7 downhole pressure of mud or other liquid within a
8 drillstring or coiled tubing at or near the lower end
9 of which the toll 100 will be mounted. Thus by
10 suitably pressurising the core 115 of the tool 100, the
11 pistons 120 can be driven radially outwards with a
12 controllable force which is proportional to the
13 pressurisation, and thereby the piston-mounted rollers
14 116 can be forced against a pipe bore in a manner to be
15 detailed below. Conversely, when the pressurisation of
16 the core 115 of the tool 100 is reduced to below
17 whatever is the ambient pressure immediately outside
18 the tool 100, the pistons 120 (together with the
19 piston-mounted rollers 116) are allowed to retract
20 radially back into their respective recesses 114.
21 (Such retraction can optionally be encouraged by
22 suitably disposed springs (not shown)).

23 The principles by which the profiling tool 100
24 functions will now be detailed with reference to Figs.
25 5 and 6.

26 Fig. 5A is a schematic end view of the three rollers
27 116 within the bore of an inner pipe 180, the remainder
28 of the tool 100 being omitted for the sake of clarity.
29 The pipe 180 is nested within an outer pipe 190 whose
30 internal diameter is somewhat greater than the outside
31 diameter of the inner pipe 180. As depicted in Fig.
32 5A, the core of the tool 100 has been pressurised just
33 sufficiently to push the pistons 120 radially outwards

1 and thereby to bring the piston-mounted rollers 116
2 into contact with the bore of the inner pipe 180, but
3 without at first exerting any significant forces on the
4 pipe 180.

5 Fig. 5B depicts the next stage of operation of the
6 profiling tool 100, in which the internal
7 pressurisation of the tool 100 is increased
8 sufficiently above its external pressure (i.e. the
9 pressure in the region between the exterior of the tool
10 100 and the bore of the pipe 180) such that the rollers
11 116 each exert a substantial outward force, as denoted
12 by the arrow-headed vectors superimposed on each roller
13 116 in Fig. 5B. The effect of such outward forces on
14 the rollers 116 is circumferentially to deform the wall
15 of the inner pipe 180 (with concomitant distortion of
16 the pipe 180 which is shown in Fig. 5B for the sake of
17 clarity). When the roller-extended lobes touch the
18 bore of the outer pipe 190, the inner pipe 180 is
19 thereby anchored against rotation with respect to the
20 outer pipe 190, or at least constrained against free
21 relative rotation. By simultaneously rotating the
22 tool 100 around its longitudinal axis (which will
23 normally be substantially coincident with the
24 longitudinal axis of the pipe 180), the circumferential
25 deformation of the wall of the pipe 180 tends to become
26 uniform around the pipe 180, and the pipe 180
27 circumferentially extends into substantially uniform
28 contact with the bore of the outer pipe 190, as
29 depicted in Fig. 5C. This occurs due to the rollers
30 causing rolling compressive yield of the inner pipe
31 wall to cause reduction in wall thickness, increase in
32 circumference and consequent increase in diameter.
33 (Rotation of the tool 100 can be undertaken by any
34 suitable procedure, several of which will subsequently

1 be described). Circumferential deformation of the pipe
2 180 is initially elastic and may subsequently be
3 plastic. A secondary effect of the process is to
4 generate compressive hoop stress in the internal
5 portion of the inner tube and an interference fit
6 between the inner tube and the outer tube.

7 From the stage depicted in Fig. 5C wherein the inner
8 pipe 180 has initially been circumferentially deformed
9 just into full contact with the bore of the outer pipe
10 190 (thus removing the previous clearance between the
11 pipes 180 and 190) but without stretching or distortion
12 of the outer pipe 190, continued (and possibly
13 increased) internal pressurisation of the tool 100 in
14 conjunction with continued rotation of the tool 100 (at
15 the same rotational speed or at a suitably different
16 rotational speed) forces the inner pipe 180 outwards
17 against the resistance to deformation of the outer pipe
18 190. Since the inner pipe 180 is now backed by the
19 outer pipe 190 with respect to the radially outward
20 forces being applied by the rollers 116 such that the
21 wall of the inner pipe 180 is now pinched between the
22 rollers 116 and the outer pipe 190, the mechanism of
23 deformation of the pipe 180 changes to compressive
24 extension by rolling (i.e. the same thinning/extension
25 principle as prevails in conventional steel rolling
26 mills, as schematically depicted in Fig. 6 wherein the
27 circular rolling of Figs. 5A-5C has been opened out and
28 developed into an equivalent straight-line rolling
29 procedure to enhance the analogy with steel rolling
30 mills).

31 When operation of the tool 100 is terminated and the
32 rollers 116 are caused or allowed to retract radially
33 into the body of the tool 100 thereby to relieve the

1 pipes 180 of all contact with the rollers 116, the
2 induced compressive hoop stress created in the wall of
3 the inner pipe 180 due to the rolling process causes
4 the inner pipe 180 to remain in contact with the inner
5 wall of the outer pipe 190 with very high contact
6 stresses at their interface.

7 Figs. 7A & 7B correspond to Figs. 5A & 5B, and
8 schematically depict the equivalent stages of operation
9 of a two-roller profiling tool (not otherwise shown per
10 se) in order to illustrate the effects of using a
11 profiling tool having fewer than the three rollers of
12 the profiling tool 100 detailed above.

13 Figs. 8A & 8B also correspond to Figs. 5A & 5B, and
14 schematically depict the equivalent stages of operation
15 of a five-roller profiling tool (not otherwise shown
16 per se) in order to illustrate the effects of using a
17 profiling tool having more than the three rollers of
18 the profiling tool 100 detailed above.

19 It should be noted that though the very high contact
20 stresses existing at the interface of the inner pipe
21 180 and outer pipe 190 may cause the outer pipe 190 to
22 expand elastically or plastically, it is not a
23 requirement of this process that the outer pipe 190 is
24 capable of any expansion whatsoever. The process would
25 still result in the high contact stresses between the
26 inner pipe 180 and the outer pipe 190 even if the outer
27 pipe 190 was incapable of expansion, eg by being thick
28 walled, by being encased in cement, or being tightly
29 embedded in a rock formation.

30 Various practical applications of profiling tools in
31 accordance with the invention will now be described.

1 with reference to Figs. 9 - 19. The profiling tool
2 used in these practical applications may be the
3 profiling tool 100 detailed above, or some variant of
4 such a profiling tool which differs in one or more
5 details without departing from the scope of the
6 invention.

7 Fig. 9A schematically depicts the upper end of a first
8 pipe or casing 200 concentrically nested within the
9 lower end of a second pipe or casing 202 whose bore
10 (internal diameter) is marginally greater than the
11 outside diameter of the first pipe or casing 200. A
12 profiling tool (not shown) is located within the upper
13 end of the first pipe or casing 200 where it is
14 overlapped by the second pipe or casing 202. The
15 rollers of the profiling tool are then radially
16 extended into contact with the bore of the inner pipe
17 or casing 200 by means of internal pressurisation of
18 the profiling tool (or by any other suitable means
19 which may alternatively be utilised for forcing the
20 rollers radially outwards of the profiling tool). The
21 outward forces exerted by the rollers on the bore of
22 the first pipe or casing 200 are schematically depicted
23 by the force-vector-depicting arrows 204.

24 From the starting situation depicted in Fig. 9A,
25 combined with suitable rotation of the profiling tool
26 about its longitudinal axis (which is substantially
27 coincident with the longitudinal axis of the first pipe
28 or casing 200), the finish situation schematically
29 depicted in Fig. 9B is arrived at, namely the upper end
30 of the inner pipe or casing 200 is profiled by
31 permanent plastic expansion into conjunction with the
32 lower end of the second pipe or casing 202. Thereby
33 the two pipes or casings are permanently conjoined

1 without the use of any form of separate connector and
2 without the use of conventional joining techniques such
3 as welding.

4 Figs. 10A & 10B correspond to Figs. 9A & 9B
5 respectively, and schematically illustrate an optional
6 modification of the profiling/conjoining technique
7 described with respect to Figs. 9A & 9B. The
8 modification consists of applying an adherent coating
9 206 of hard particulate material to the exterior of the
10 upper end of the first (inner) pipe or casing 200 prior
11 to its location within the lower end of the second
12 (outer) pipe or casing 202. The hard particulate
13 material may consist of carbide granules, e.g. tungsten
14 carbide granules such as are commonly used to coat
15 downhole reamers. In the application depicted in Figs.
16 10A & 10B, the hard particulate material is selected
17 for its crush resistance rather than for its abrasive
18 qualities, and in particular the material is selected
19 for its ability to interpenetrate the meeting surfaces
20 of two sheets of steel which are pressed together with
21 the hard particulate material sandwiched between the
22 steel components. Such sandwiching is schematically
23 depicted in Fig. 10B. Tests have shown a surprising
24 increase in resistance to separation forces of pipes or
25 other articles conjoined by a profiling tool in
26 accordance with the invention to withstand, where a
27 coating of hard particulate material was first
28 interposed between the parts being conjoined. It is
29 preferred that of the whole area to be coated, only a
30 minority of the area is actually covered with the
31 particulate material, e.g. 10% of the area. (It is
32 believed that a higher covering factor actually reduces
33 the interpenetration effect and hence diminishes the
34 benefits below the optimum level).

1 Referring now to Figs. 11A & 11B, these schematically
2 depict an optional modification of the Fig. 9
3 conjoining procedure to achieve improved sealing.
4 between the two conjoined pipes or casings. As
5 depicted in Fig. 11A, the modification comprises
6 initially fitting the exterior of the first (inner)
7 pipe or casing 200 with a circumferentially extending
8 and part-recessed ductile metal ring 208, which may
9 (for example) be formed of a suitable copper alloy or a
10 suitable tin/lead alloy. The modification also
11 comprises initially fitting the exterior of the first
12 (inner) pipe or casing 200 with a circumferentially
13 extending and fully recessed elastomeric ring 210. As
14 depicted in Fig. 11B, the rings 208 and 210 become
15 crushed between the two pipes or casings 200 & 202
16 after these have been conjoined by the profiling tool,
17 and thereby a mutual sealing is achieved which may be
18 expected to be superior to the basic Fig. 9 arrangement
19 in otherwise equal circumstances. In suitable
20 situations, one or other of the sealing rings 208 and
21 210 may be omitted or multiplied to achieve a necessary
22 or desirable level of sealing (e.g. as in Fig. 12).

23 Referring now to Figs. 12A & 12B, these schematically
24 depict an arrangement in which the lower end of the
25 second (outer) casing 202 is pre-formed to have a
26 reduced diameter so as to function as a casing hanger.
27 The upper end of the first (inner) casing 200 is
28 correspondingly pre-formed to have an increased
29 diameter which is complementary to the reduced diameter
30 of the casing hanger formed at the lower end of the
31 outer casing 202, as depicted in Fig. 12A. Optionally,
32 the upper end of the first (inner) casing 200 may be
33 provided with an external seal in the form of an
34 elastomeric ring 212 flush-mounted in a circumferential

1 groove formed in the outer surface of the first casing
2 200. The arrangement of Fig. 12A differs from the
3 arrangement of Fig. 9A in that the latter arrangement
4 requires the pipe or casing 200 to be positively held
5 up (to avoid dropping down the well out of its intended
6 position) until joined to the upper pipe or casing as
7 in Fig. 9B, whereas in the Fig. 12A arrangement the
8 casing hanger allows the inner/lower casing 200 to be
9 lowered into position and then released without the
10 possibility of dropping out of position prior to the
11 two casings being conjoined by the profiling tool, as
12 depicted in Fig. 12B.

13 Referring now to Figs. 13A & 13B, these schematically
14 depict another optional modification of the Fig. 9
15 conjoining procedure in order to achieve a superior
16 resistance to post-conjunction separation. As depicted
17 in Fig. 13A, the modification consists of initially
18 forming the bore (inner surface) of the second (outer)
19 pipe or casing 202 with two circumferentially extending
20 grooves 214 each having a width which reduces with
21 increasing depth. As depicted in Fig. 13B, when the
22 two pipes or casings 200 and 202 have been conjoined by
23 the profiling tool (as detailed with respect to Figs.
24 9A & 9B), the first (inner) pipe or casing 200 will
25 have been plastically deformed into the grooves 214,
26 thereby increasing the interlocking of the conjoined
27 pipes or casings and extending their resistance to
28 post-conjunction separation. While two grooves 214 are
29 shown in Figs. 13A & 13B by way of example, this
30 procedure can in suitable circumstances be carried with
31 one such groove, or with three or more such grooves.
32 While each of the grooves 214 has been shown with a
33 preferred trapezoidal cross-section, other suitable
34 groove cross-sections can be substituted.

1 The superior joint strength of the Fig. 13 arrangement
2 can be combined with the superior sealing function of
3 the Fig. 11 arrangement, as shown in Fig. 14. Fig. 14A
4 schematically depicts the pre-jointing configuration,
5 in which the exterior of the first (inner) pipe or
6 casing 200 is fitted with a longitudinally spaced pair
7 of circumferentially extending and part-recessed
8 ductile metal rings 208, while the bore (inner surface)
9 of the second (outer) pipe or casing 202 is formed with
10 two circumferentially extending grooves 214 each having
11 a width which reduces with increasing depth. The
12 longitudinal spacing of the two grooves 214 is
13 substantially the same as the longitudinal spacing of
14 the seal rings 208. When the two pipes or casings are
15 conjoined by use of the profiling tool (as
16 schematically depicted in Fig. 14B), the first (inner)
17 pipe or casing 200 is not only plastically deformed
18 into the corresponding grooves 214 (as in Fig. 13B),
19 but the metal rings 208 are crushed into the bottoms of
20 these grooves 214 thereby to form high grade metal-to-
21 metal seals.

22 In the arrangements of Figs. 9 - 14, it is assumed that
23 the second (outer) pipe or casing 202 undergoes little
24 or no permanent deformation, which may either be due to
25 the outer pipe or casing 202 being inherently rigid
26 compared to the first (inner) pipe or casing 200, or be
27 due to the outer pipe or casing being rigidly backed
28 (e.g. by cured concrete filling the annulus around the
29 outer pipe or casing 202), or be due to a combination
30 of these and/or other reasons. Fig. 15 schematically
31 depicts an alternative situation in which the second
32 (outer) pipe or casing 202 does not have the previously
33 assumed rigidity. As schematically depicted in Fig.
34 15A, the pre-jointing configuration is merely a variant

1 of the previously described pipe-joining arrangements,
2 in which the exterior of the upper end of the first
3 (inner) pipe or casing 200 is provided with two part-
4 recessed metal seal rings 208 (each mounted in a
5 respective circumferential groove), neither pipe being
6 otherwise modified from its initial plain tubular
7 shape. To conjoin the casings 200 and 202, the
8 profiling tool is operated in a manner which forces the
9 second (outer) casing 202 through its elastic limit and
10 into a region of plastic deformation, such that when
11 the conjoining process is completed, both casings
12 retain a permanent outward set as depicted in Fig. 15B.

13 In each of the arrangements described with reference to
14 Figs. 9 - 15, the bore of the first pipe or casing 200
15 was generally smaller than the bore of the second pipe
16 or casing 202. However, there are situations where it
17 would be necessary or desirable that these bores be
18 about mutually equal following conjoining, and this
19 requires variation of the previously described
20 arrangements, as will now be detailed.

21 In the arrangement schematically depicted in Fig. 16A,
22 the lower end of the second (outer) pipe or casing 202
23 is pre-formed to have an enlarged diameter, the bore
24 (inside diameter) of this enlarged end being marginally
25 greater than the outside diameter of the first (inner)
26 pipe or casing 200 intended to be conjoined thereto.
27 The first (inner) pipe or casing 200 has initial
28 dimensions which are similar or identical to those of
29 the second pipe or casing 202 (other than for the
30 enlarged end of the pipe or casing 202). Following use
31 of the profiling tool to expand the overlapping ends of
32 the two pipes or casings, both bores have about the
33 same diameter (as depicted in Fig. 16B) which has

1 certain advantages (e.g. a certain minimum bore at
2 depth in a well no longer requires a larger or much
3 larger bore at lesser depth in the well). While
4 surface-level pipes can be extended in this manner
5 without difficulties in adding extra lengths of pipe,
6 special techniques may be necessary for feeding
7 successive lengths of casing to downhole locations when
8 extending casing in a downhole direction. (One
9 possible solution to this requirement may be provide
10 successive lengths of casing with a reduced diameter,
11 and to expand the entire length of each successive
12 length of casing to the uniform bore of previously
13 installed casing, this being achievable by further
14 aspects of the invention to be subsequently described
15 by way of example with reference to Figs. 20 et seq).

16 A modification of the procedure and arrangement of Fig.
17 16 is schematically depicted in Fig. 17 wherein the end
18 of the outer pipe or casing is not pre-formed to an
19 enlarged diameter (Fig. 17A). It is assumed in this
20 case that the profiling tool is capable of exerting
21 sufficient outward force through its rollers as to be
22 capable of sufficiently extending the diameter of the
23 outer pipe or casing simultaneously with the diametral
24 extension of the inner pipe or casing during forming of
25 the joint (Fig. 17B).

26 As well as conjoining pipes or casings, the profiling
27 tool in accordance with the invention can be utilised
28 for other useful purposes such as will now be detailed
29 with reference to Figs. 18 and 19.

30 In the situation schematically depicted in Fig. 18, a
31 riser 220 has a branch 222 which is to be blocked off
32 while continuing to allow free flow of fluid along the

1 riser 220. To meet this requirement, a sleeve 224 is
2 placed within the riser 220 in position to bridge the
3 branch 222. The sleeve 224 initially has an external
4 diameter which is just sufficiently less than the
5 internal diameter of the riser 220 as to allow the
6 sleeve 224 to be passed along the riser to its required
7 location. Each end of the sleeve 224 is provided with
8 external seals 226 of any suitable form, e.g. the seals
9 described with reference to Fig. 11. When the sleeve
10 224 is correctly located across the branch 222, a
11 profiling tool (not shown in Fig. 18) is applied to
12 each end of the sleeve 224 to expand the sleeve ends
13 into mechanically anchoring and fluid-sealing contact
14 with the bore of the riser 220, thus permanently
15 sealing the branch (until such time as the sleeve may
16 be milled away or a window may be cut through it).

17 Fig. 19 schematically depicts another alternative use
18 of the profiling tool in accordance with the invention,
19 in which a valve requires to be installed within plain
20 pipe or casing 240 (i.e. pipe or casing free of landing
21 nipples or other means of locating and anchoring
22 downhole equipment). A valve 242 of a size to fit
23 within the pipe or casing 240 has a hollow tubular
24 sleeve 244 welded or otherwise secured to one end of
25 the valve. The sleeve 244 initially has an external
26 diameter which is just sufficiently less than the
27 internal diameter of the pipe or casing 240 as to allow
28 the mutually attached valve 242 and sleeve 244 to
29 pass down the pipe or casing 240 to the required
30 location. The end of the sleeve 244 opposite to the
31 end attached to the valve 242 is provided with external
32 seals 246 of any suitable form, e.g. the seals
33 described with reference to Fig. 11. When the valve
34 242 is correctly located where it is intended to be

1 installed, a profiling tool (not shown in Fig. 19) is
2 applied to the end of the sleeve opposite the valve 242
3 to expand that end of the sleeve 244 into mechanically
4 anchoring and fluid-sealing contact with the bore of
5 the pipe or casing 240. An optional modification of
6 the Fig. 19 arrangement is to attach an expandable
7 sleeve to both sides of the valve such that the valve
8 can be anchored and sealed on either side instead of
9 one side only as in Fig. 19.

10 Turning now to Fig. 20, this illustrates a side
11 elevation of an embodiment of expansion tool 300 in
12 accordance with the present invention. The expansion
13 tool 300 is an assembly of a primary expansion tool 302
14 and a secondary expansion tool 304, together with a
15 connector sub 306 which is not essential to the
16 invention but which facilitates mechanical and
17 hydraulic coupling of the expansion tool 300 to the
18 downhole end of a drillstring (not shown) or to the
19 downhole end of coiled tubing (not shown). The primary
20 expansion tool 302 is shown separately and to an
21 enlarged scale in Fig. 21 (and again, in exploded view,
22 in Fig. 21A). The expansion tool 300 is shown in
23 longitudinal section in Fig. 22, the primary expansion
24 tool 302 is shown separately in longitudinal section in
25 Fig. 23, and the secondary expansion tool 304 is shown
26 separately in an exploded view in Fig. 24.

27 From Figs. 20 - 24 it will be seen that the general
28 form of the primary expansion tool 302 is that of a
29 roller tool externally presenting a conical array of
30 four tapered rollers 310 tapering towards an imaginary
31 point (not denoted) ahead of the leading end of the
32 expansion tool 300, i.e. the right end of the tool 300
33 as viewed in Figs. 20 & 21. As may be more clearly

1 seen in Figs. 21A, 22, & 23, the rollers 310 run on a
2 conical race 312 integrally formed on the surface of
3 the body of the primary expansion tool 302, the rollers
4 being constrained for true tracking by a
5 longitudinally slotted cage 314. An end retainer 316
6 for the rollers 310 is secured on the screw-threaded
7 leading end 318 of the primary expansion tool 302 by
8 means of a ring nut 320. The trailing end 322 of the
9 primary expansion tool 302 is screw-threaded into the
10 leading end 106 of the secondary expansion tool 304 to
11 form the composite expansion tool 300. Functioning of
12 the primary expansion tool 300 will be detailed
13 subsequently.

14 The secondary expansion tool 304 is substantially
15 identical to the previously detailed profiling tool 100
16 (except for one important difference which is described
17 below), and accordingly those parts of the secondary
18 expansion tool 304 which are the same as corresponding
19 parts of the profiling tool 100 (or which are obvious
20 modifications thereof) are given the same reference
21 numerals. The important difference in the secondary
22 expansion tool 304 with respect to the profiling tool
23 100 is that the rotation axes of the rollers 116 are no
24 longer exactly parallel to the longitudinal axis of the
25 tool, but are skewed such that each individual roller
26 rotation axis is tangential to a respective imaginary
27 helix, though making only a small angle with respect to
28 the longitudinal direction (compare Fig. 24 with Fig.
29 4). As particularly shown in Figs. 20 and 24, the
30 direction (or "hand") of the skew of the rollers 116 in
31 the secondary expansion tool 304 is such that the
32 conventional clockwise rotation of the tool (as viewed
33 from the uphole end of the tool, i.e. the left end as
34 viewed in Figs. 20 & 22) is such as to induce a

1 reaction against the bore of the casing (not shown in
2 Figs. 20 - 24) which tends not only to rotate the tool
3 300 around its longitudinal axis but also to advance
4 the tool 300 in a longitudinal direction, i.e. to drive
5 the tool 300 rightwards as viewed in Figs. 20 & 22.
6 (The use of skewed bore-contacting rollers to cause a
7 rotating downhole tool to drive itself along a casing
8 is detailed in the afore-mentioned WO93/24728-A1).

9 In use of the expansion tool 300 to expand casing (not
10 shown) previously deployed to a selected downhole
11 location in a well, the tool 300 is lowered on a
12 drillstring (not shown) or coiled tubing (not shown)
13 until the primary expansion tool 302 at the leading end
14 of the tool 300 engages the uphole end of the
15 unexpanded casing. The core of the tool 300 is
16 pressurised to force the roller-carrying pistons 120
17 radially outwards and hence to force the rollers 116
18 into firm contact with the casing bore. The tool 300
19 is simultaneously caused to rotate clockwise (as viewed
20 from its uphole end) by any suitable means (e.g. by
21 rotating the drillstring (if used), or by actuating a
22 downhole mud motor (not shown) through which the tool
23 300 is coupled to the drillstring or coiled tubing),
24 and this rotation combines with the skew of the rollers
25 116 of the secondary tool 304 to drive the tool 300 as
26 a whole in the downhole direction. The conical array
27 of rollers 310 in the primary expansion tool 302 forces
28 its way into the uphole end of the unexpanded casing
29 where the combination of thrust (in a downhole
30 direction) and rotation rolls the casing into a conical
31 shape that expands until its inside diameter is just
32 greater than the maximum diameter of the array of
33 rollers 310 (i.e. the circumscribing diameter of the
34 array of rollers 310 at its upstream end). Thereby the

1 primary expansion tool 302 functions to bring about the
2 primary or initial expansion of the casing.

3 The secondary expansion tool 304 (which is immediately
4 uphole of the primary expansion tool 302) is internally
5 pressurised to a pressure which not only ensures that
6 the rollers 116 contact the casing bore with sufficient
7 force as to enable the longitudinal traction force to
8 be generated by rotation of the tool about its
9 longitudinal axis but also forces the pistons 120
10 radially outwards to an extent that positions the
11 piston-carried rollers 116 sufficiently radially
12 distant from the longitudinal axis of the tool 304
13 (substantially coincident with the centreline of the
14 casing) as to complete the diametral expansion of the
15 casing to the intended final diameter of the casing.
16 Thereby the secondary expansion tool 304 functions to
17 bring about the secondary expansion of the casing.
18 (This secondary expansion will normally be the final
19 expansion of the casing, but if further expansion of
20 the casing is necessary or desirable, the expansion
21 tool 300 can be driven through the casing again with
22 the rollers 116 of the secondary expansion tool set at
23 a greater radial distance from the longitudinal axis of
24 the tool 304, or a larger expansion tool can be driven
25 through the casing). While the primary expansion tool
26 302 with its conical array of rollers 310 is preferred
27 for initial expansion of casing, the secondary
28 expansion tool 304 with its radially adjustable rollers
29 has the advantage that the final diameter to which the
30 casing is expanded can be selected within a range of
31 diameters. Moreover, this final diameter can not only
32 be adjusted while the tool 304 is static but can also
33 be adjusted during operation of the tool by suitable
34 adjustment of the extent to which the interior of the

1 tool 304 is pressurised above the pressure around the
2 outside of the tool 304. This feature also gives the
3 necessary compliance to deal with variances in wall
4 thickness

5 Fig. 25 is a longitudinal section of a primary
6 expansion tool 402 which is a modified version of the
7 primary expansion tool 302 (detailed above with
8 reference to Figs. 20 - 24). Components of the tool
9 402 which correspond to components of the tool 302 are
10 given the same reference numeral except that the
11 leading "3" is replaced by a leading "4". The tool 402
12 is essentially the same as the tool 302 except that the
13 rollers 410 are longer than the rollers 310, and the
14 conical race 412 has a cone angle which is less than
15 the cone angle of the race 312 (i.e. the race 412
16 tapers less and is more nearly cylindrical than the
17 race 312). As shown in Fig. 25, the trailing (uphole)
18 end of the tool 402 is broken away. For details of
19 other parts of the tool 402, reference should be made
20 to the foregoing description of the tool 302. In
21 contrast to Figs. 20 - 24, Fig. 25 also shows a
22 fragment of casing 480 which is undergoing expansion by
23 the tool 402.

24 Fig. 26 is a longitudinal section of a primary
25 expansion tool 502 which is a further-modified version
26 of the primary expansion tool 302. Components of the
27 tool 502 which correspond to components of the tool 302
28 are given the same reference numeral except that the
29 leading "3" is replaced by a leading "5". The tool 502
30 is identical to the tool 402 except that the rollers
31 510 have a length which is somewhat less than the
32 length of the rollers 410. This reduced length allows
33 the rollers 510 some longitudinal freedom within their

1 windows in the cage 514. Consequently, although
2 expansion operation of the primary expansion tool 502
3 is essentially identical to operation of the primary
4 expansion tool 410 (and similar to operation of the
5 primary expansion tool 310 except for functional
6 variations occasioned by the different conicities of
7 the respective races), reversal of longitudinal thrust
8 on the tool 502 (i.e. pulling the tool 502 uphole
9 instead of pushing the tool 502 downhole) will cause or
10 allow the rollers 510 to slide along the conical race
11 512 in the direction of its reducing diameter, thus
12 allowing the rollers 510 radially to retract from the
13 casing bore as illustrated in Fig. 26. Such roller
14 retraction frees the tool 502 from the casing 480 and
15 permits free withdrawal of the tool 502 in an uphole
16 direction whereas the non-retracting rollers 410 of the
17 tool 402 might possibly jam the tool 402 within the
18 casing 480 in the event of attempted withdrawal of the
19 tool 402.

20 Turning now to Fig. 27, this is a simplified
21 longitudinal elevation of a casing expander assembly
22 600 for use in downhole expansion of a solid, slotted
23 or imperforate metal tube 602 within a casing 604 which
24 lines a well. The casing expander assembly 600 is a
25 three-stage expansion tool which is generally similar
26 (apart from the number of expansion stages) to the two-
27 stage expansion tool 300 described above with reference
28 to Figs. 20 - 24.

29 In order from its leading (downhole) end, the expander
30 assembly 600 comprises a running/guide assembly 610, a
31 first-stage conical expander 612, an inter-stage
32 coupling 614, a second-stage conical expander 616, a
33 further inter-stage coupling 618, and a third-stage

1 cylindrical expander 620.

2 The first-stage conical expander 612 comprises a
3 conical array of tapered rollers which may be the same
4 as either one of the primary expansion tools 302 or
5 402, or which differs therefrom in respect of the
6 number of rollers and/or in respect of the cone angles
7 of the rollers and their race.

8 The second-stage conical expander 616 is an enlarged-
9 diameter version of the first-stage conical expander
10 612 dimensioned to provide the intermediate expansion
11 stage of the three-stage expansion assembly 600. The
12 diameter of the leading (narrow) end of the second-
13 stage expander 616 (the lower end of the expander 616
14 as viewed in Fig. 27) is marginally less than the
15 diameter of the trailing (wide) end of the first-stage
16 expander 612 (the upper end of the expander 612 as
17 viewed in Fig. 27) such that the second-stage expander
18 616 is not precluded from entering initially expanded
19 tube 602 resulting from operation of the first-stage
20 expander 612.

21 The third-stage expander 620 is a generally cylindrical
22 expander which may be similar either to the profiling
23 tool 100 or to the secondary expansion tool 304.
24 (Although the rollers of the third-stage expander 620
25 may be termed "cylindrical" in order to facilitate
26 distinction over the conical rollers of the first-stage
27 and second-stage expanders 612 & 616, and although in
28 certain circumstances such so-called "cylindrical"
29 rollers may in fact be truly cylindrical, the rollers
30 of the cylindrical expander will usually be barrelled
31 to avoid excessive end stresses). The rollers of the
32 third-stage expander 620 will normally be radially

1 extended from the body of the expander 620 by an extent
2 that the third-stage expander 620 rolls the tube 602
3 into its final extension against the inside of casing
4 604, such that no further expansion of the tube 602 is
5 required in the short term.

6 The inter-stage couplings 614 and 618 can be
7 constituted by any suitable arrangement that
8 mechanically couples the three expander stages, and
9 (where necessary or desirable) also hydraulically
10 couples the stages.

11 The rollers of the third-stage expander 620 may be
12 skewed such that rotation of the assembly 600 drives
13 the assembly in a downhole direction; alternatively,
14 the rollers may be unskewed and forward thrust on the
15 expanders be provided by suitable weights, e.g. by
16 drill collars 630 immediately above the assembly 600.
17 Where the third-stage rollers are skewed, drill collars
18 can be employed to augment the downhole thrust provided
19 by rotation of the assembly 600.

20 As depicted in Fig. 27, the three-stage expander
21 assembly 600 is suspended from a drillstring 640 which
22 not only serves for transmitting rotation to the
23 assembly 600 but also serves for transmitting hydraulic
24 fluid under pressure to the assembly 600 for radial
25 extension of the third-stage rollers, for cooling the
26 assembly 600 and newly deformed tube 602, and for
27 flushing debris out of the work region.

28 In suitable circumstances, the drillstring 640 may be
29 substituted by coiled tubing (not shown) of a form
30 known per se.

1 Turning now to Fig. 28 (which is divided into three
2 mutually related Figs. 28A, 28B, & 28C), these
3 illustrate a primary expansion tool 702 which may be
4 summarised as being the primary expansion tool 402
5 (Fig. 25) with hard steel bearing balls 710 substituted
6 for the rollers 410. Each of the balls 710 runs in a
7 respective circumferential groove 712, and is located
8 for proper tracking by a suitably perforated cage 714.
9 As with the tool 402, the cage 714 is retained by a
10 retainer 716 secured on the screw-threaded leading end
11 718 of the tool 702 by means of a ring nut 720.
12 Operation of the tool 702 is functionally similar to
13 operation of the tool 402, as is illustrated by the
14 expansion effect of the tool 702 on casing 480.

15 The primary expansion tool 702 as shown in Figs. 28A -
16 28C could be modified by the substitution of the series
17 of circumferential ball tracks 712 with a single spiral
18 track (not shown) around which the balls 710 would
19 circulate at ever-increasing radii to create the
20 requisite expansion forces on the casing. At the point
21 of maximum radius, the balls 710 would be recirculated
22 back to the point of minimum radius (near the leading
23 end of the tool 702, adjacent the retainer 716) by
24 means of a channel (not shown) formed entirely within
25 the central body of the tool 702 in a form analogous to
26 a recirculating ball-screw (known per se).

27 Figs. 29A & 29B illustrate a modification 802 of the
28 ball-type expansion primary expansion tool 702 of Fig.
29 28 analogous to the Fig. 26 modification 502 of the
30 Fig. 25 roller-type primary expansion tool 402. In the
31 modified ball-type primary expansion tool 802, the hard
32 steel bearing balls 810 run in longitudinally-extending
33 grooves 812 instead of the circumferential grooves 712

1 of the tool 702. The ball-guiding perforations in the
2 cage 814 are longitudinally extended into slots which
3 allow individual balls 810 to take up different
4 longitudinal positions (and hence different effective
5 radii) according to whether the tool 802 is being
6 pushed downhole (Fig. 28A) or being pulled uphole (Fig.
7 28B). In the latter case, the balls 810 are relieved
8 from pressure on the surrounding casing 480 and thereby
9 obviate any risk of the tool 802 becoming jammed in
10 partly-expanded casing.

11 In the profiling and expansion tools with controllably
12 displaceable rollers as previously described, e.g. with
13 reference to Figs. 4 and 24, the ability to obtain and
14 to utilise hydraulic pressure may place practical
15 limits on the forces which can be exerted by the
16 rollers. Fig. 30 illustrates a roller-type
17 expansion/profiling tool 900 which utilises a
18 mechanical force-multiplying mechanism to magnify a
19 force initially produced by controlled hydraulic
20 pressure, and to apply the magnified force to
21 profiling/expanding rollers 902. Each of the plurality
22 of rollers 902 (only two being visible in Fig. 30) has
23 a longitudinally central portion which is near-
24 cylindrical and slightly barrelled (i.e. slightly
25 convex), bounded on either side by end portions which
26 are conical, both end portions tapering from
27 conjunction with the central portion to a minimum
28 diameter at each end. Rotation of each roller 902
29 about a respective rotation axis which is parallel to
30 the longitudinal axis of the tool 900 and at a
31 controllably variable radial displacement therefrom is
32 ensured by a roller-guiding cage 904 of suitable form.

33 The effective working diameter of the tool 900 is

1 dependent on the (normally equal) radial displacements
2 of the rollers 902 from the longitudinal axis of the
3 tool 900 (such displacement being shown at a minimum in
4 Fig. 30). The conical end portions of each roller 902
5 each run on a respective one of two conical races 906
6 and 908 whose longitudinal separation determines the
7 radial displacement of the rollers 902. The conical
8 races 906 and 908 are coupled for synchronous rotation
9 but variable separation by means of a splined shaft 910
10 which is rigid with the upper race 906 and non-
11 rotatably slid able in the lower race 908. The tool 900
12 has a hollow core which hydraulically couples through
13 an upper sub 912 to a drillstring (not shown) which
14 both selectively rotates the tool 900 within
15 surrounding casing 990 which is to be profiled/expanded
16 by the tool 900 and transmits controllable hydraulic
17 pressure to the core of the tool 900 for controlling
18 the roller displacement as will now be detailed.

19 The lower end of the tool 900 (with which the lower
20 race 908 is integral) is formed as hollow cylinder 914
21 within which a piston 916 is slidably sealed. The
22 piston 916 is mounted on the lower end of a downward
23 extension of the shaft 910 which is hollow to link
24 through the tool core and the drillstring to the
25 controlled hydraulic pressure. The piston 916 divides
26 the cylinder 914 into upper and lower parts. The upper
27 part of the cylinder 914 is linked to the controlled
28 hydraulic pressure by way of a side port 918 in the
29 hollow shaft 910, just above the piston 916. The lower
30 part of the cylinder 914 is vented to the outside of
31 the tool 900 through a hollow sub 920 which constitutes
32 the lower end of the tool 900 (and which enables
33 further components, tools, or drillstring (not shown))
34 to be connected below the tool 900). Thereby a

1 controllable hydraulic pressure differential can be
2 selectively created across the piston 916, with
3 consequent control of the longitudinal separation of
4 the two roller-supporting conical races 906 and 908
5 which in turn controls the effective rolling diameter
6 of the tool 900.

7 While certain modifications and variations of the
8 invention have been described above, the invention is
9 not restricted thereto, and other modifications and
10 variations can be adopted without departing from the
11 scope of the invention as defined in the appended
12 claims.

1 CLAIMS :

2 1. A method of profiling a pipe or other hollow tubular
3 article, the method comprising the steps of applying a
4 roller means to a part of the pipe bore selected to be
5 profiled, translating the roller means across the bore
6 in a direction including a circumferential component
7 while applying a force to the roller means in a
8 radially outwards direction with respect to the
9 longitudinal axis of the pipe, and continuing such
10 translation and force application until the pipe is
11 plastically deformed substantially into the intended
12 profile.

13 2. A method according to claim 1 wherein the
14 deformation of the pipe is accomplished by radial
15 compression of the pipe wall, or by circumferential
16 stretching of the pipe wall, or by a combination of
17 such radial compression and circumferential stretching.

18 3. A method according to claim 1 or claim 2 wherein
19 said direction is purely circumferential.

20 4. A method according to claim 1 or claim 2 wherein
21 said direction is partly circumferential and partly
22 longitudinal.

23 5. A method according to any preceding claim wherein
24 said roller means is peripherally profiled to be
25 complementary to the profile into which the selected
26 part of the pipe bore is intended to be formed.

27 6. A method according to any preceding claim wherein
28 the selected part of the pipe bore is remote from an
29 open end of the pipe, and the method comprises the

1 further steps of inserting the roller means into the
2 open end of the pipe (if the roller means is not
3 already in the pipe), and transferring the roller means
4 along the pipe to the selected location.

5

6 7. A method as claimed in claim 6 wherein transfer of
7 the roller means is accomplished by the step of
8 actuating traction means coupled to or forming part of
9 the roller means and effective to apply along-pipe
10 traction forces to the roller means by reaction against
11 parts of the pipe bore adjacent the roller means.

12 8. A method of conjoining two pipes or other hollow
13 tubular articles, said method comprising the steps of
14 locating one of the two pipes within and longitudinally
15 overlapping one of the other of the two pipes, applying
16 roller means to a part of the bore of the inner of the
17 two pipes at a location where it is intended that the
18 two pipes be conjoined, translating the roller means
19 across the bore in a direction including a
20 circumferential component while applying a radially
21 outwardly directed force to the roller means, and
22 continuing such translation and force application until
23 the inner pipe is plastically deformed into permanent
24 contact with the outer pipe and is thereby conjoined
25 thereto.

26 9. A method according to claim 8 wherein said
27 deformation is accomplished by radial compression of
28 the pipe wall, or by circumferential stretching of the
29 pipe wall, or by a combination of such radial
30 compression and circumferential stretching.

31 10. A method according to claim 8 or claim 9 wherein
32 said direction is purely circumferential.

- 1 11. A method according to claim 8 or claim 9 wherein
2 said direction is partly circumferential and partly
3 longitudinal.
- 4 12. A method according to any of claims 8 to 11 wherein
5 the location where the pipes are intended to be
6 conjoined is remote from an accessible end of the bore,
7 and the method comprises the further steps of inserting
8 the roller means into the accessible end of the bore
9 (if the roller means is not already in the bore), and
10 transferring the roller means to the intended location.
- 11 13. A method according to claim 12 wherein transfer of
12 the roller means is accomplished by the step of
13 actuating traction means coupled to or forming part of
14 the roller means and effective to apply along-bore
15 traction forces to the roller means by reaction against
16 parts of the pipe bore adjacent the roller means.
- 17 14. Apparatus for expanding a pipe or other hollow
18 tubular article, said apparatus comprising roller means
19 constructed or adapted for rolling deployment against
20 the bore of the pipe, said roller means comprising at
21 least one set of individual rollers each mounted for
22 rotation about a respective rotation axis which is
23 generally parallel to the longitudinal axis of the
24 apparatus, the rotation axes of said at least one set
25 of rollers being circumferentially distributed around
26 the expansion apparatus and each being radially offset
27 from the longitudinal axis of the expansion apparatus,
28 the expansion apparatus being selectively rotatable
29 around its longitudinal axis.
- 30 15. Apparatus according to claim 14 wherein the
31 rotation axes of said at least one set of rollers

1 conform to a first regime in which each said rotation
2 axis is substantially parallel to the longitudinal axis
3 of the apparatus in a generally cylindrical
4 configuration.

5 16. Apparatus according to claim 14 wherein the
6 rotation axes of said at least one set of rollers
7 conform to a second regime in which each said rotation
8 axis lies substantially in a respective radial plane
9 including the longitudinal axis of the apparatus and
10 the rotation axes each converge substantially towards a
11 common point substantially on the longitudinal axis of
12 the apparatus in a generally conical configuration.

13 17. Apparatus according to claim 14 wherein the
14 rotation axes of said at least one set of rollers
15 conform to a third regime in which each said rotation
16 axis is similarly skewed with respect to the
17 longitudinal axis of the apparatus in a generally
18 helical configuration which is either non-convergent
19 (cylindrical) or convergent (conical).

20 18. Apparatus according to any of claims 14 to 17
21 wherein the apparatus has only a single such set of
22 rollers.

23 19. Apparatus according to any of claims 14 to 17
24 wherein the apparatus has a plurality of such sets of
25 rollers.

26 20. Apparatus according to claim 19 wherein the sets of
27 rollers conform to two or more different ones of the
28 three regimes of roller axis alignments defined in
29 claims 15-17.

- 1 21. Apparatus according to claim 20 wherein the
- 2 apparatus has a set of rollers conforming to the second
- 3 regime located at leading end of the apparatus and
- 4 another set of rollers conforming to the first regime
- 5 located elsewhere on the apparatus.
- 6 22. Apparatus according to claim 21 modified by the
- 7 addition of a further set of rollers conforming to
- 8 third regime with non-convergent axes, this further set
- 9 of rollers being utilised for the purpose of applying
- 10 traction forces to the apparatus.
- 11 22. Apparatus according to any of claims 14 to 21
- 12 wherein the rollers of said apparatus are each mounted
- 13 for rotation about its respective rotation axis
- 14 substantially without freedom of movement along its
- 15 respective rotation axis.
- 16 23. Apparatus according to any of claims 14 to 21
- 17 wherein the rollers of said apparatus are each mounted
- 18 for rotation about its respective rotation axis with
- 19 freedom of movement along its respective rotation axis,
- 20 24. Apparatus according to claim 23 wherein said
- 21 rollers have freedom of movement which is constrained
- 22 within predetermined limits of movement.
- 23 25. Apparatus for profiling or conjoining pipes or
- 24 other hollow tubular articles, said apparatus
- 25 comprising roller means and radial urging means
- 26 selectively operable to urge the roller means radially
- 27 outwards of a longitudinal axis of the apparatus, the
- 28 radial urging means causing or allowing the roller
- 29 means to move radially inwards towards the longitudinal
- 30 axis of the apparatus when the radial urging means is

1 not operated, the roller means comprising a plurality
2 of individual rollers each mounted for rotation about a
3 respective rotation axis which is substantially
4 parallel to the longitudinal axis of the apparatus, the
5 rotation axes of the individual rollers being
6 circumferentially distributed around the apparatus and
7 each said rotation axis being radially offset from the
8 longitudinal axis of the apparatus, the apparatus being
9 selectively rotatable around its longitudinal axis to
10 translate the roller means across the bore of a pipe
11 against which the roller means is being radially urged.
12

13 26. Apparatus according to claim 25 wherein the radial
14 urging means comprises a respective piston on which
15 each said roller is individually rotatably mounted,
16 each said piston being slidably sealed in a respective
17 radially extending bore formed in a body of the
18 apparatus, a radially inner end of each said bore being
19 in fluid communication with fluid pressure supply means
20 selectively pressurisable to operate said radial urging
21 means.

22 27. Apparatus according to claim 25 wherein the radial
23 urging means comprises bi-conical race means upon which
24 each said individual roller rolls in use of the
25 apparatus, and separation variation means selectively
26 operable controllably to vary the longitudinal
27 separation of the two conical races of the bi-conical
28 race means whereby correspondingly to vary the radial
29 displacement of each said roller rotation axis from the
30 longitudinal axis of the apparatus.

31 28. Apparatus according to claim 27 wherein the
32 separation variation means comprises hydraulic linear
33 motor means selectively pressurisable to drive one of

1 said two cones longitudinally towards and/or away from
2 the other said cone.

3 29. A method of expanding an inner pipe into an outer
4 pipe, said method comprising effecting rolling
5 compressive yield of the wall of the inner pipe wall to
6 cause reduction in wall thickness and subsequent
7 increase in circumference resulting in diameter
8 increase.

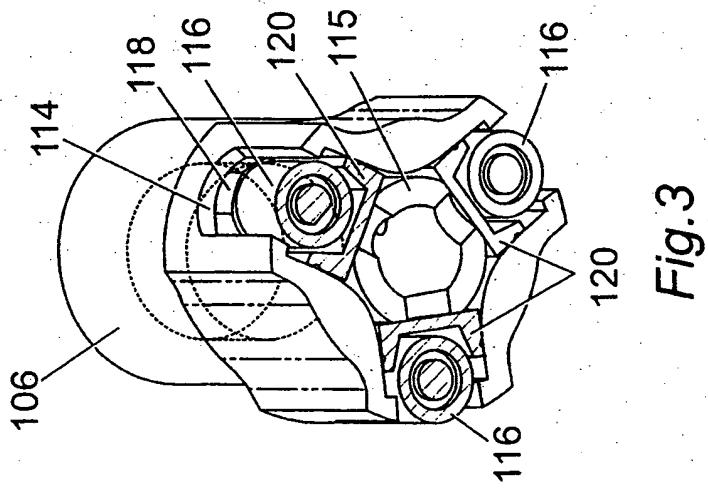
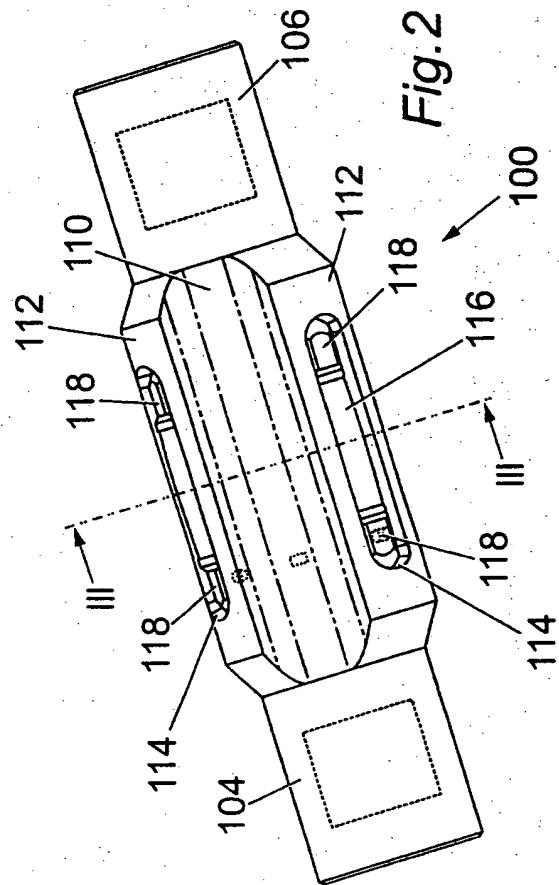
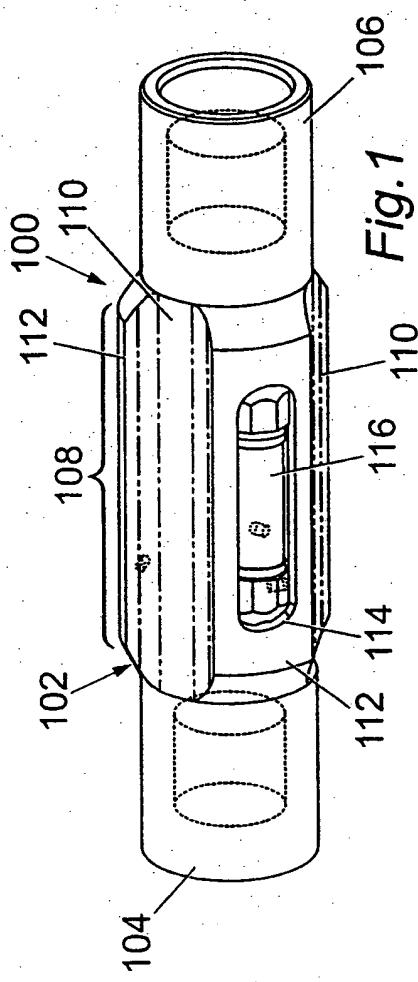
9 30. A method as claimed in Claim 29, wherein the method
10 generates compressive hoop stress in the inner pipe
11 resulting in an interference fit of the inner pipe
12 within the outer pipe.

13 31. A method as claimed in Claim 30, wherein the
14 resulting interference fit can withstand a high level
15 of longitudinal force resulting from tensile or
16 compressive stress.

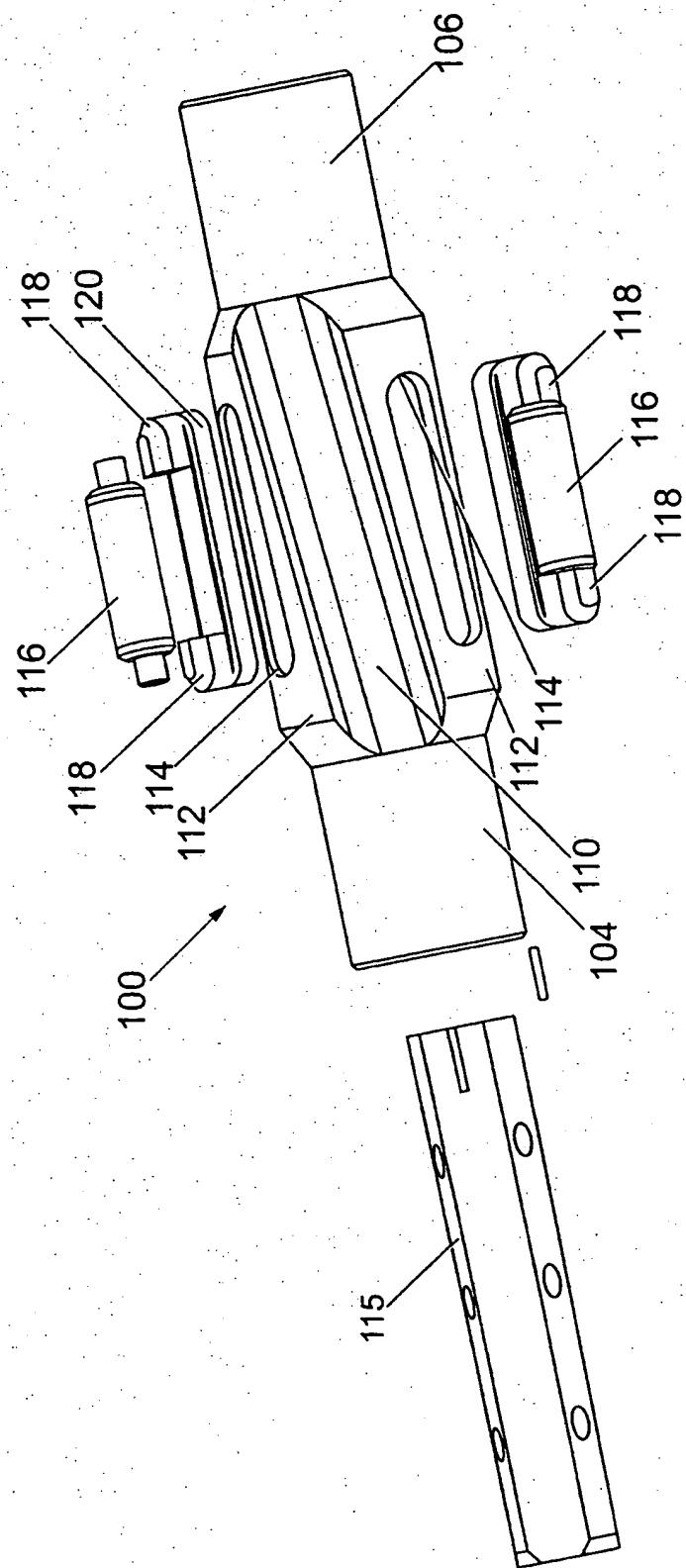
17 32. A method of creating a high pressure seal between
18 an inner pipe and an outer pipe by creating a metal to
19 metal interface between the pipes by effecting rolling
20 compressive yield of the inner pipe within the outer
21 pipe.

22 33. A method as claimed in Claim 32, including the
23 addition of elastomer or ductile metal seals between
24 the inner pipe and outer pipe.

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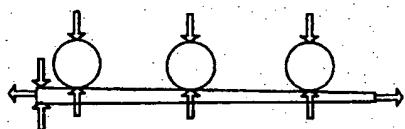
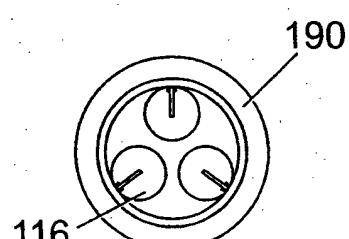
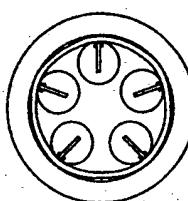
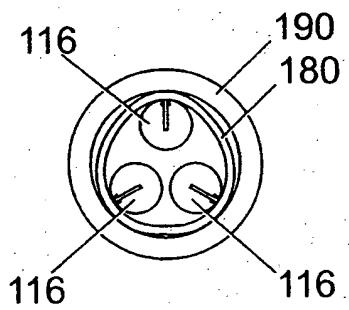
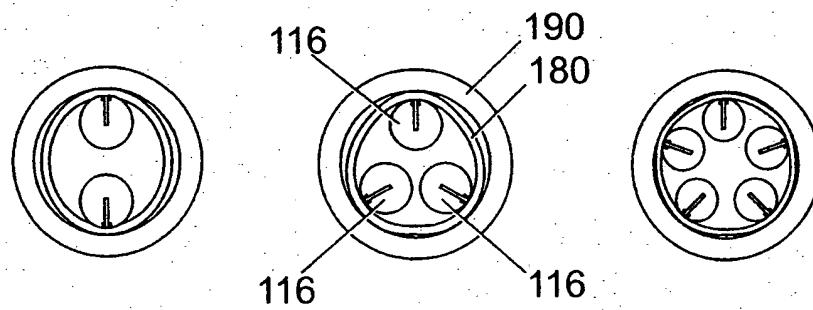
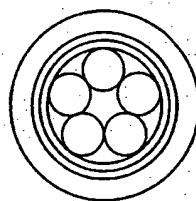
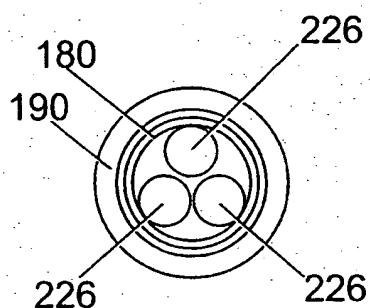
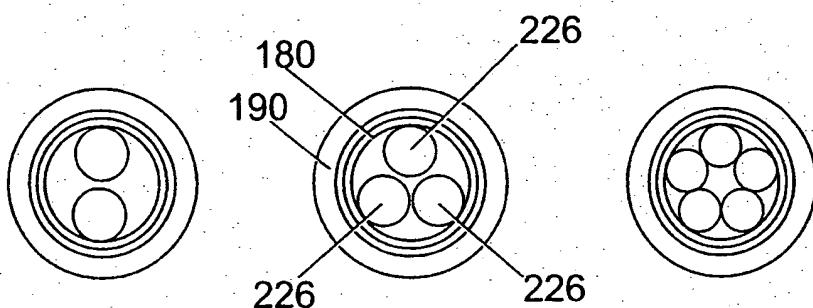


Fig. 6



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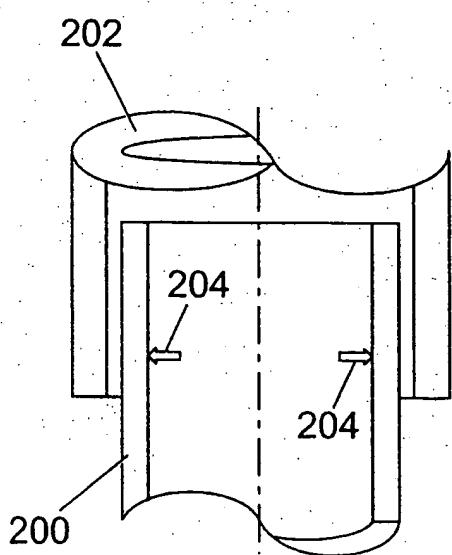


Fig. 9a

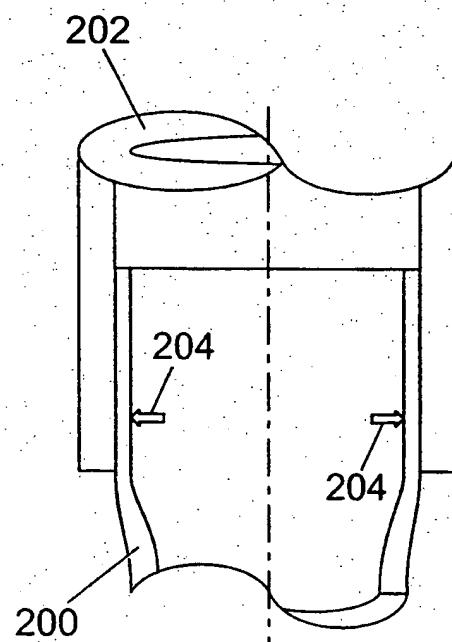


Fig. 9b

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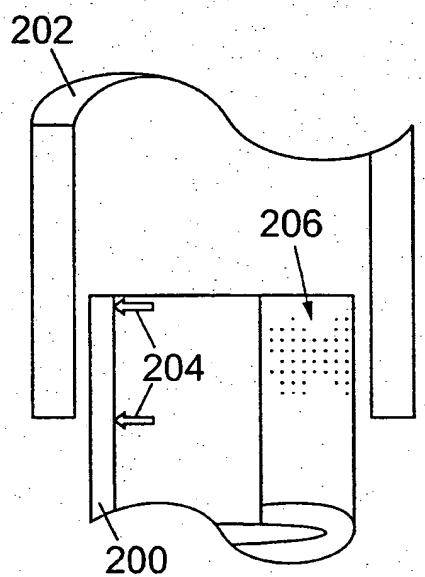


Fig. 10a

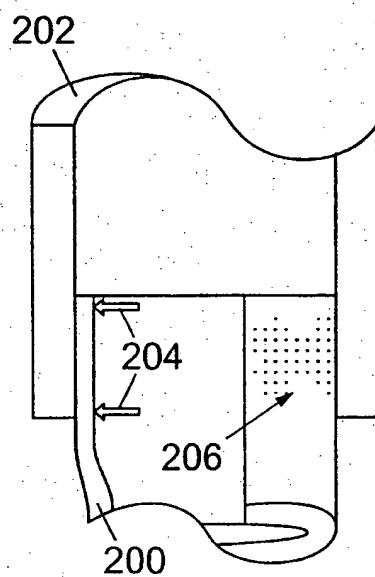


Fig. 10b

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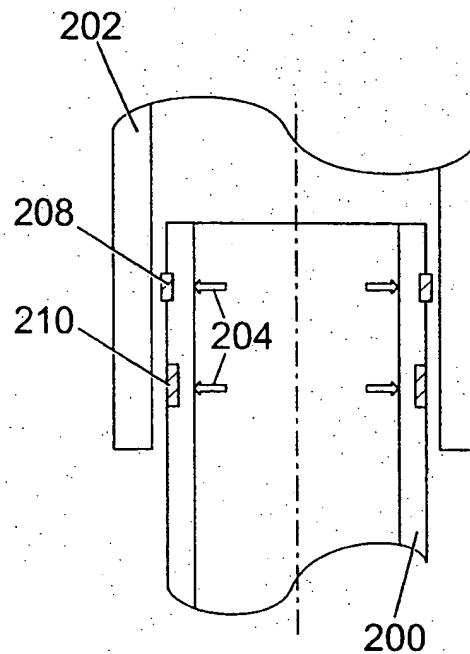


Fig. 11a

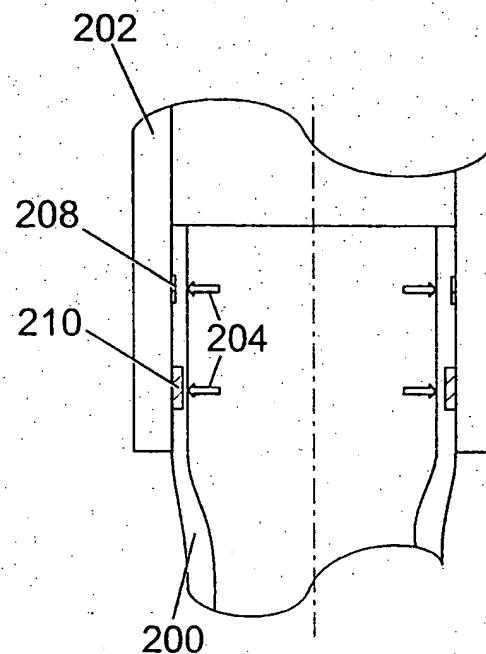


Fig. 11b

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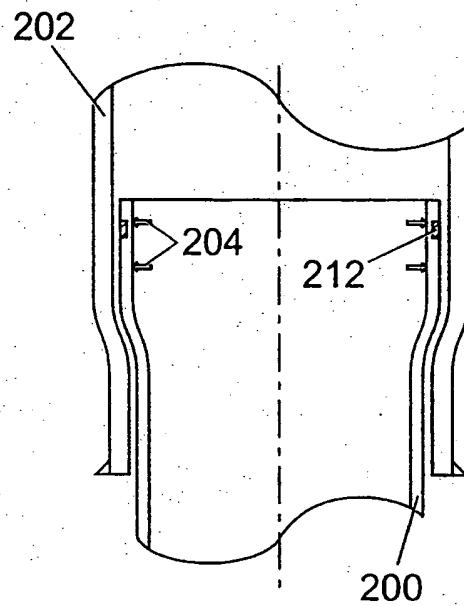


Fig. 12a

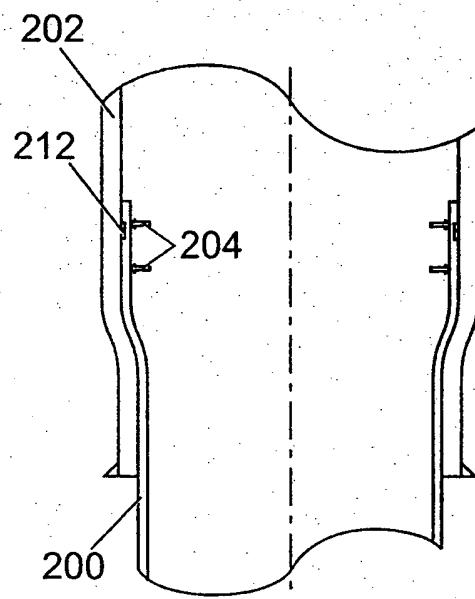


Fig. 12b

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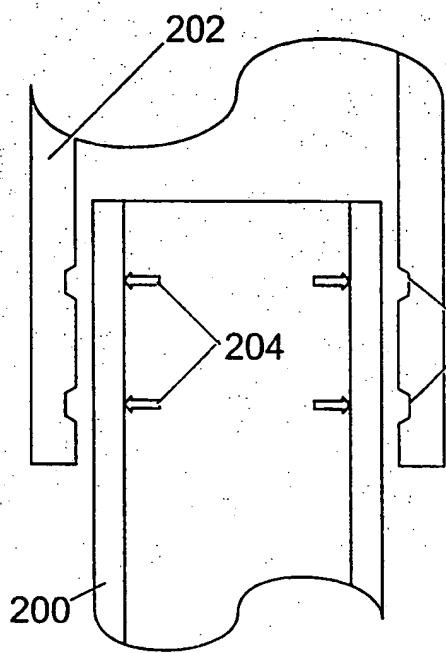


Fig. 13a

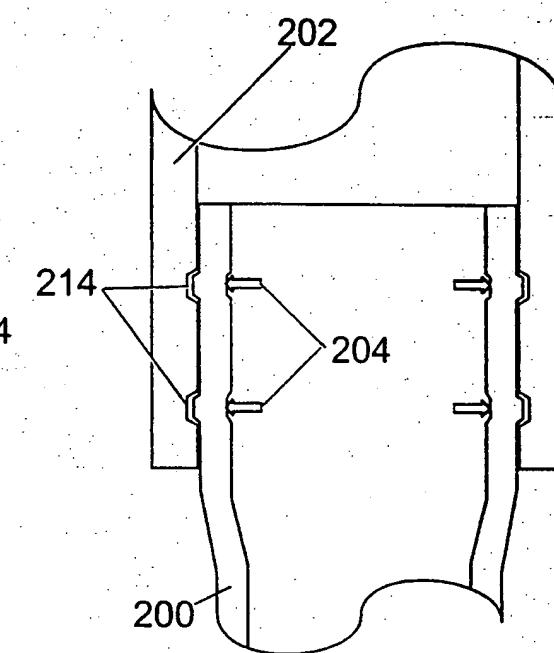


Fig. 13b

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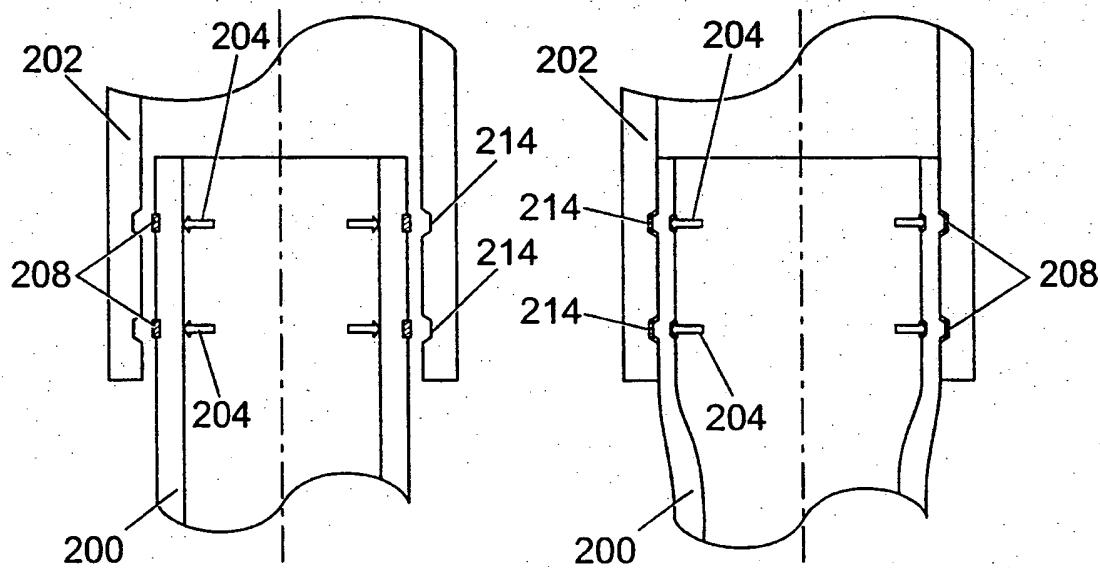


Fig. 14a

Fig. 14b

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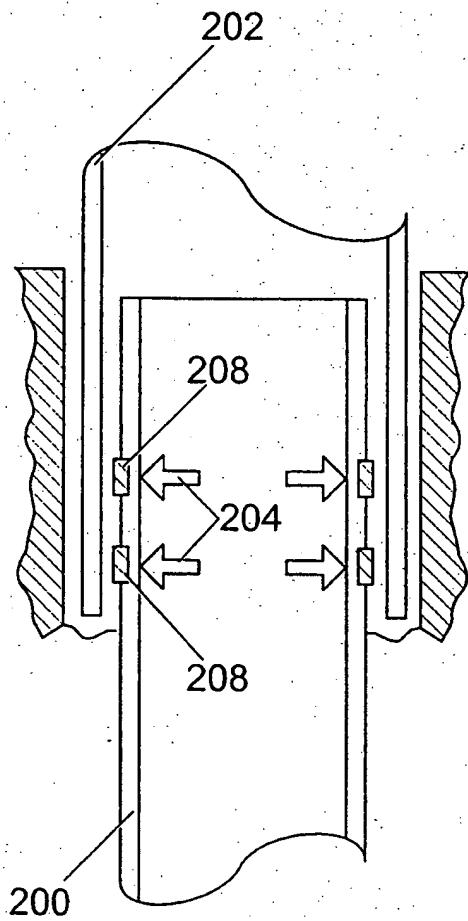


Fig. 15a

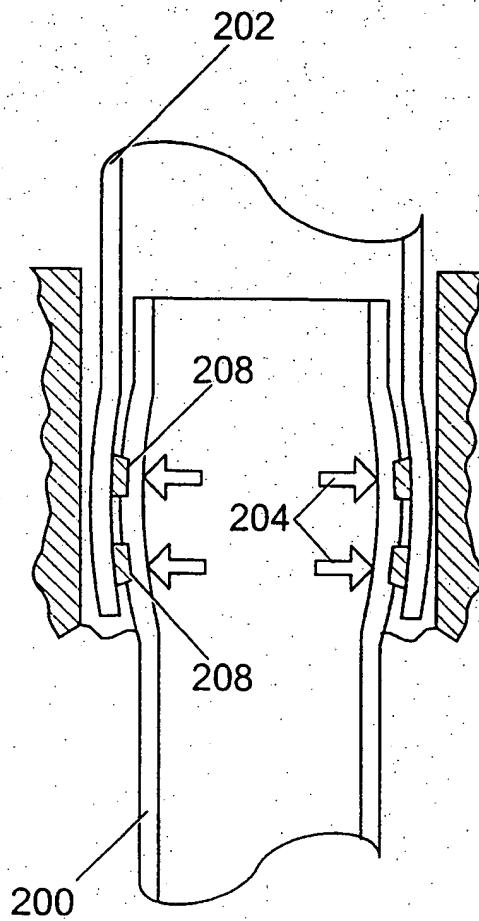


Fig. 15b

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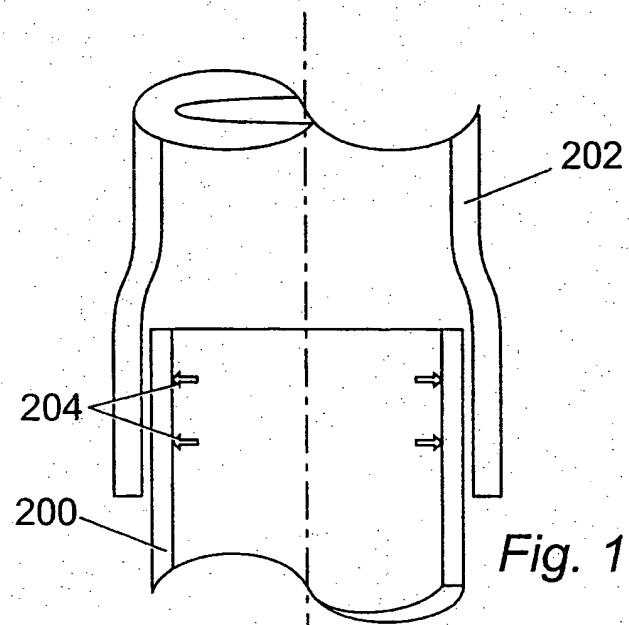


Fig. 16a

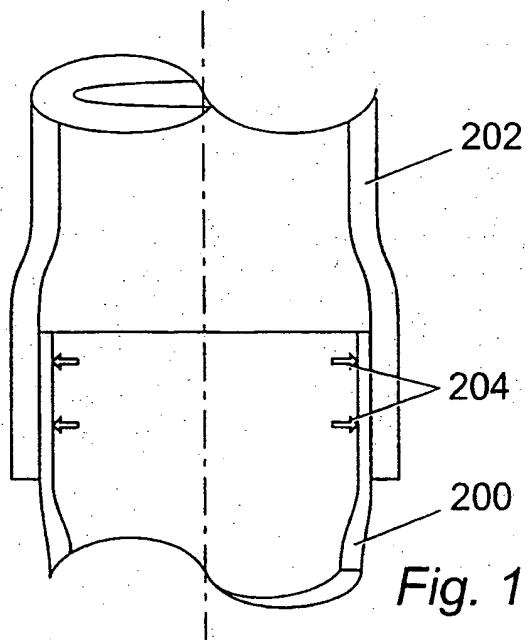


Fig. 16b

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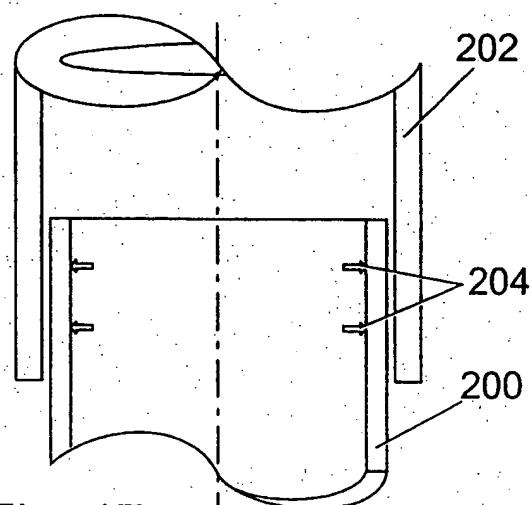


Fig. 17a

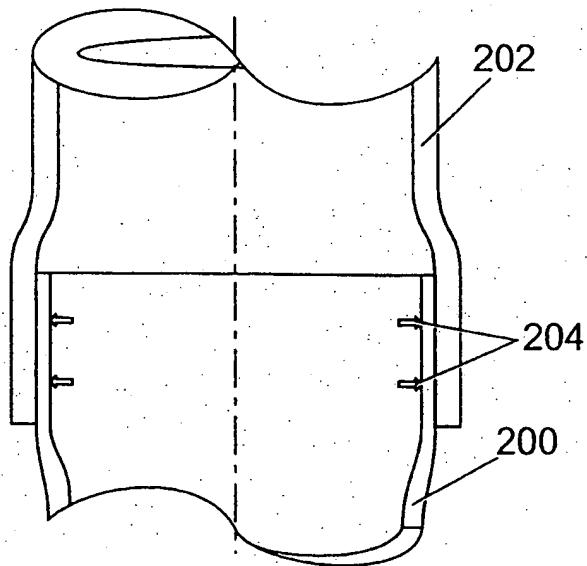


Fig. 17b

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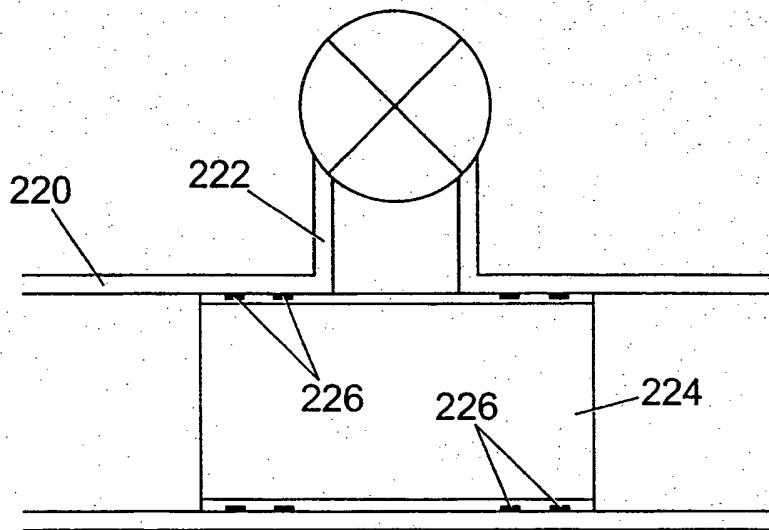


Fig. 18

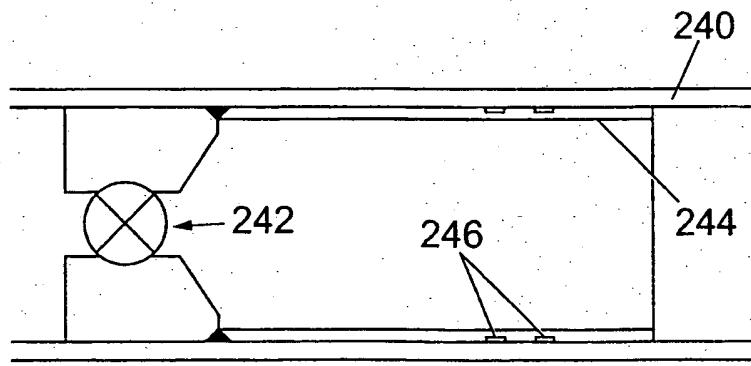


Fig. 19

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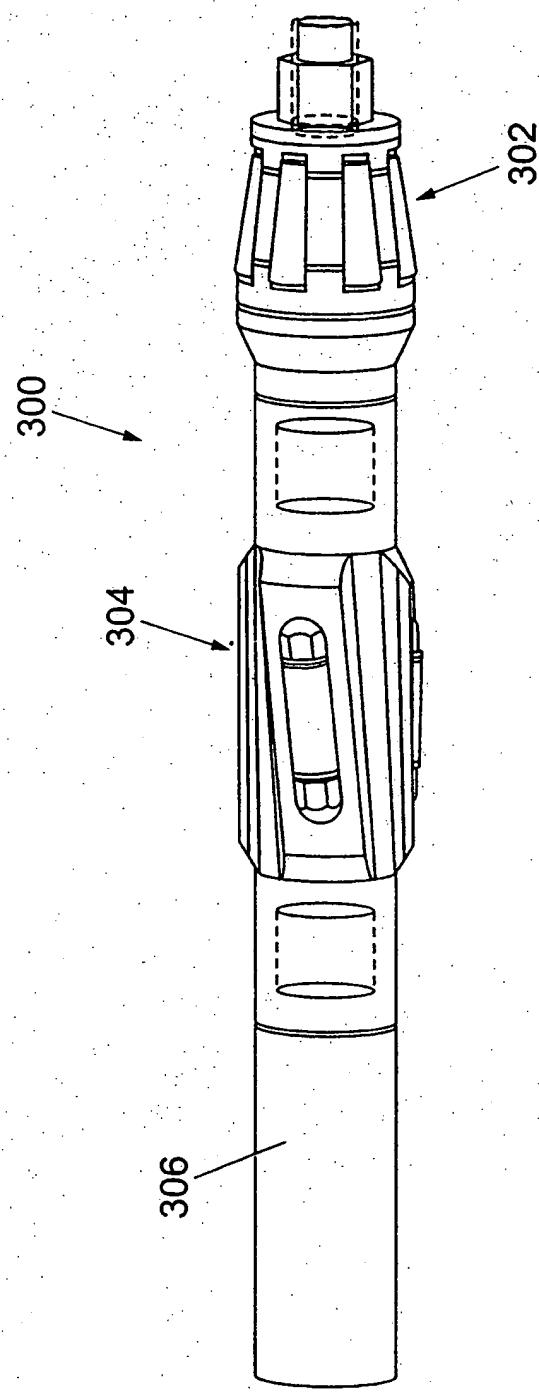


Fig. 20

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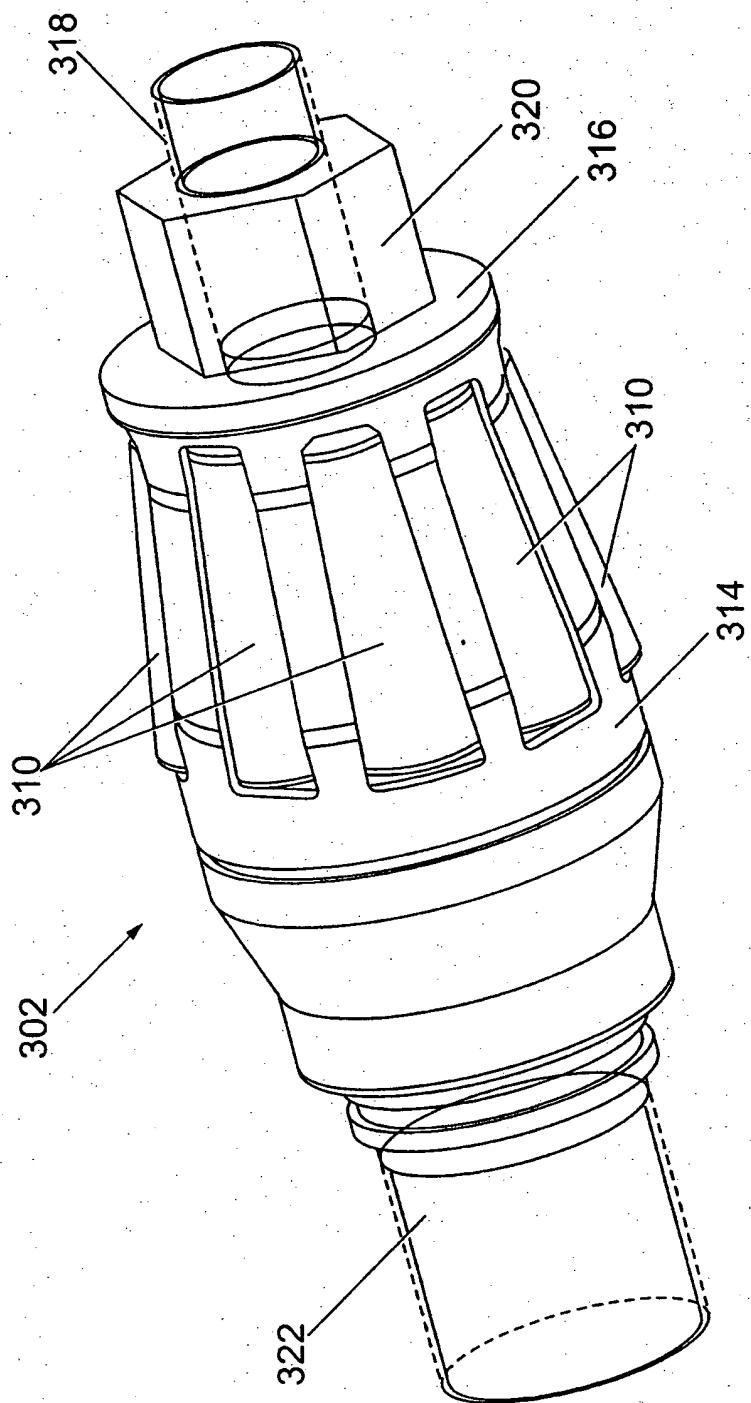


Fig. 21

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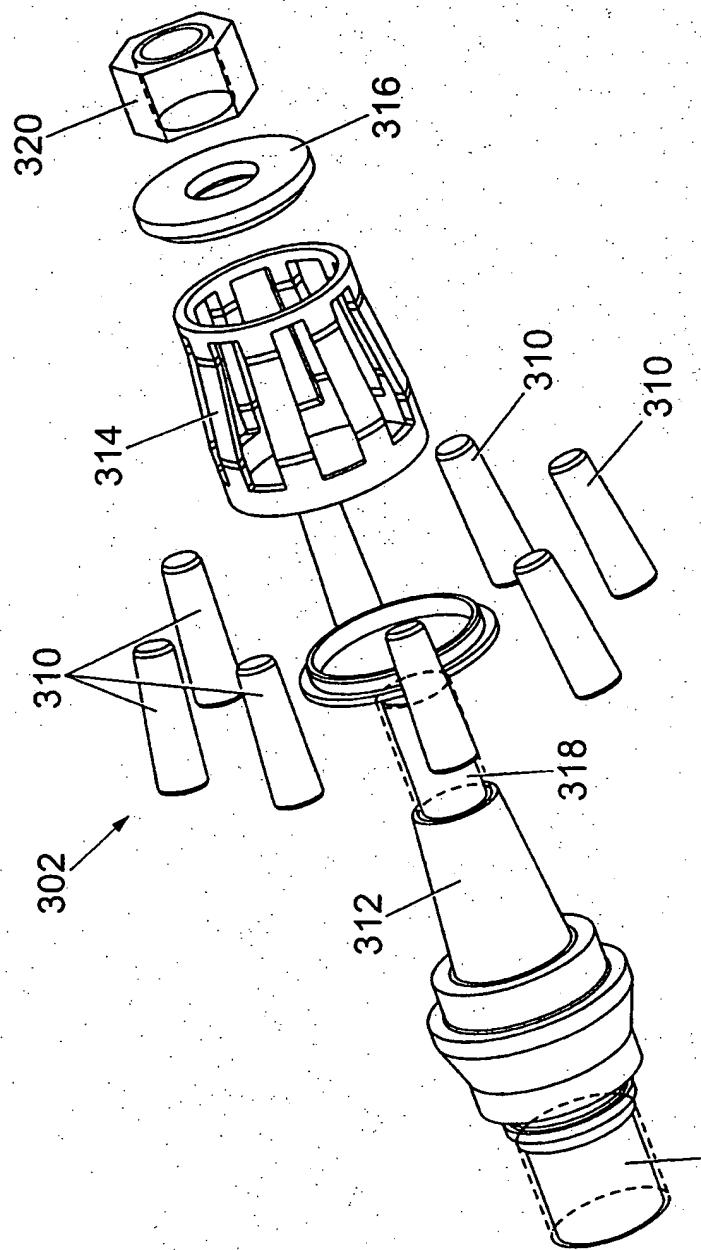


Fig. 21a

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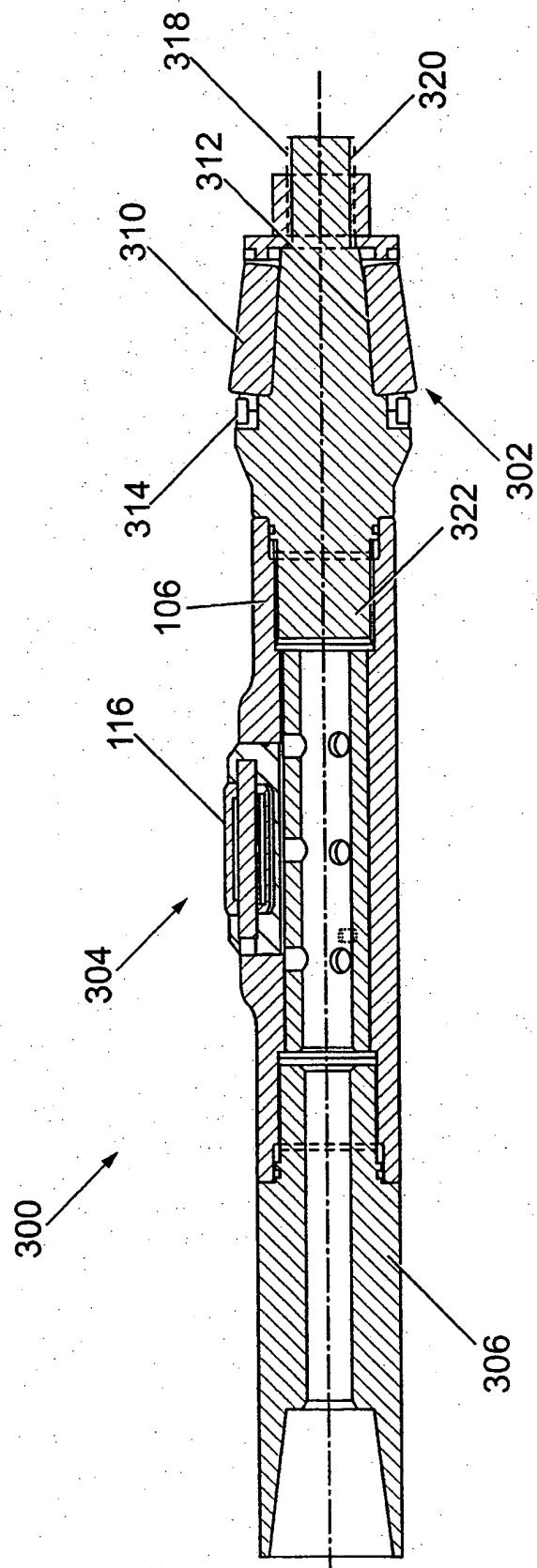


Fig. 22

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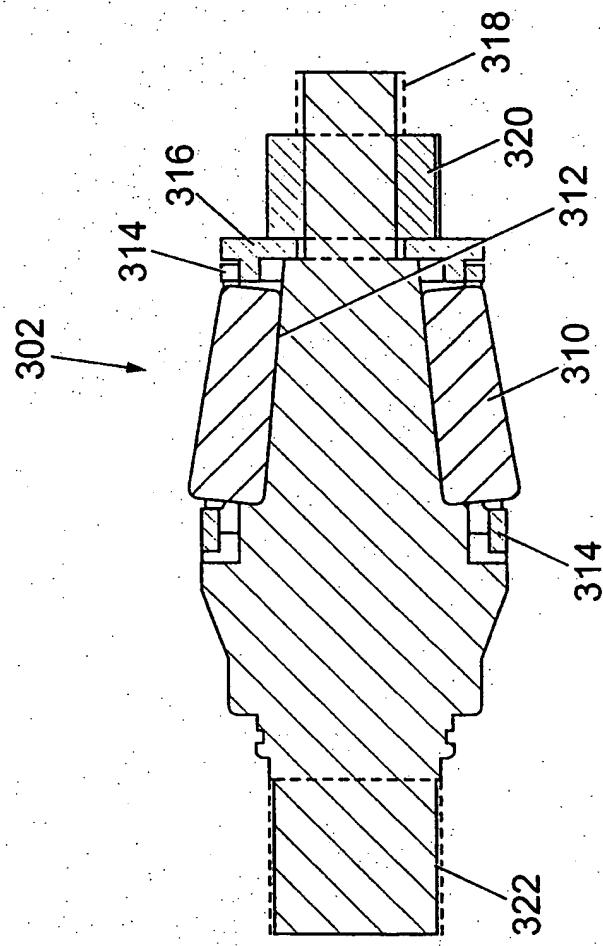


Fig. 23

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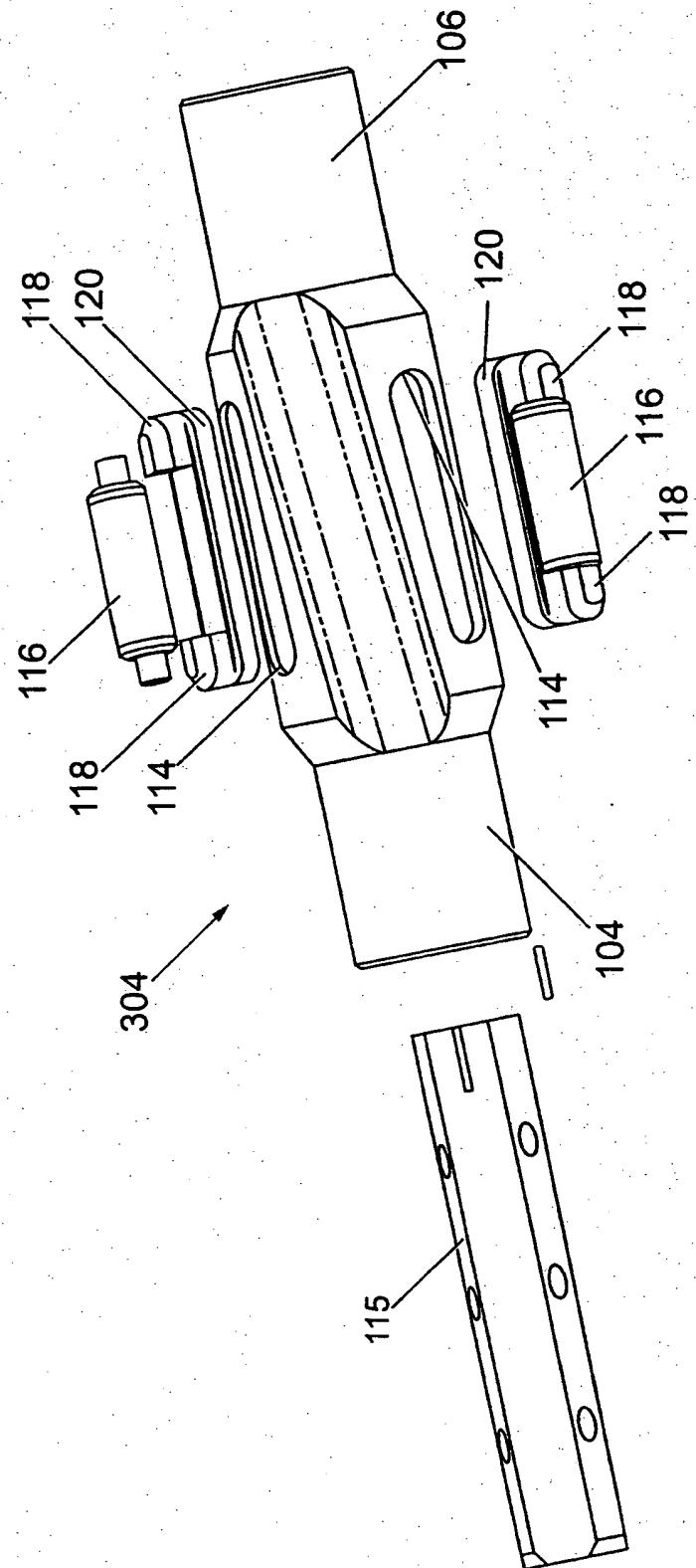


Fig. 24

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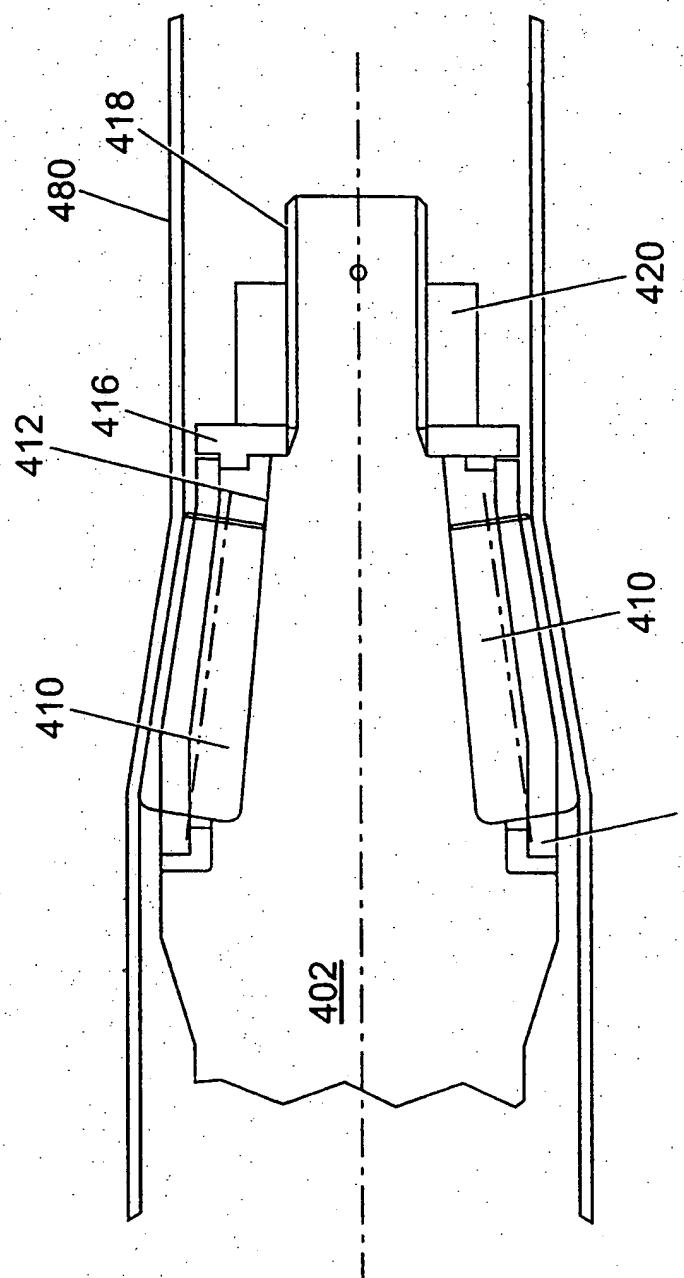


Fig. 25

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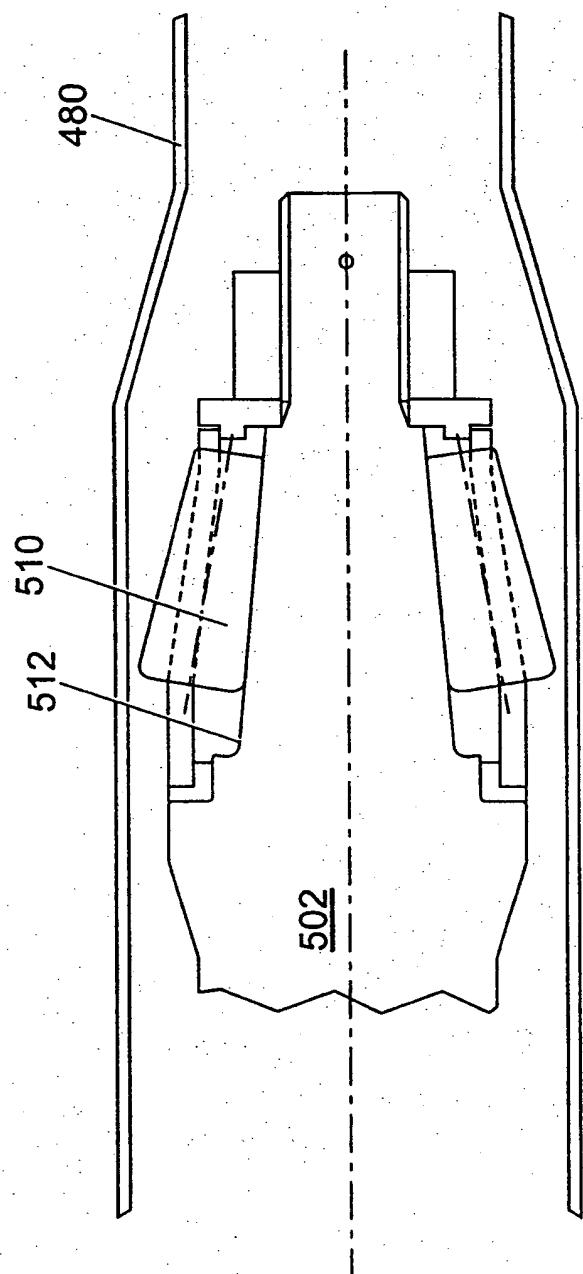


Fig. 26

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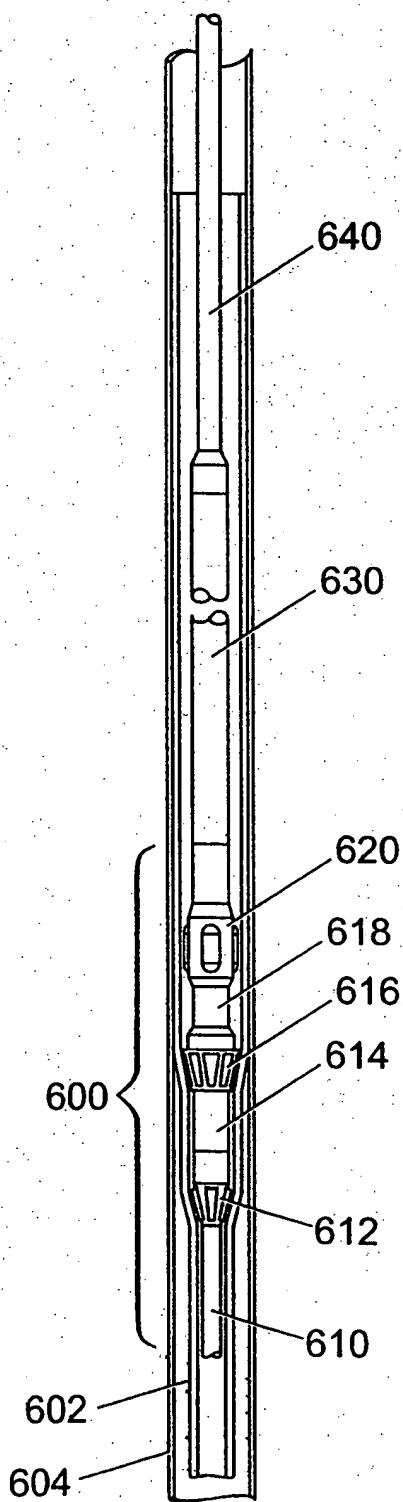
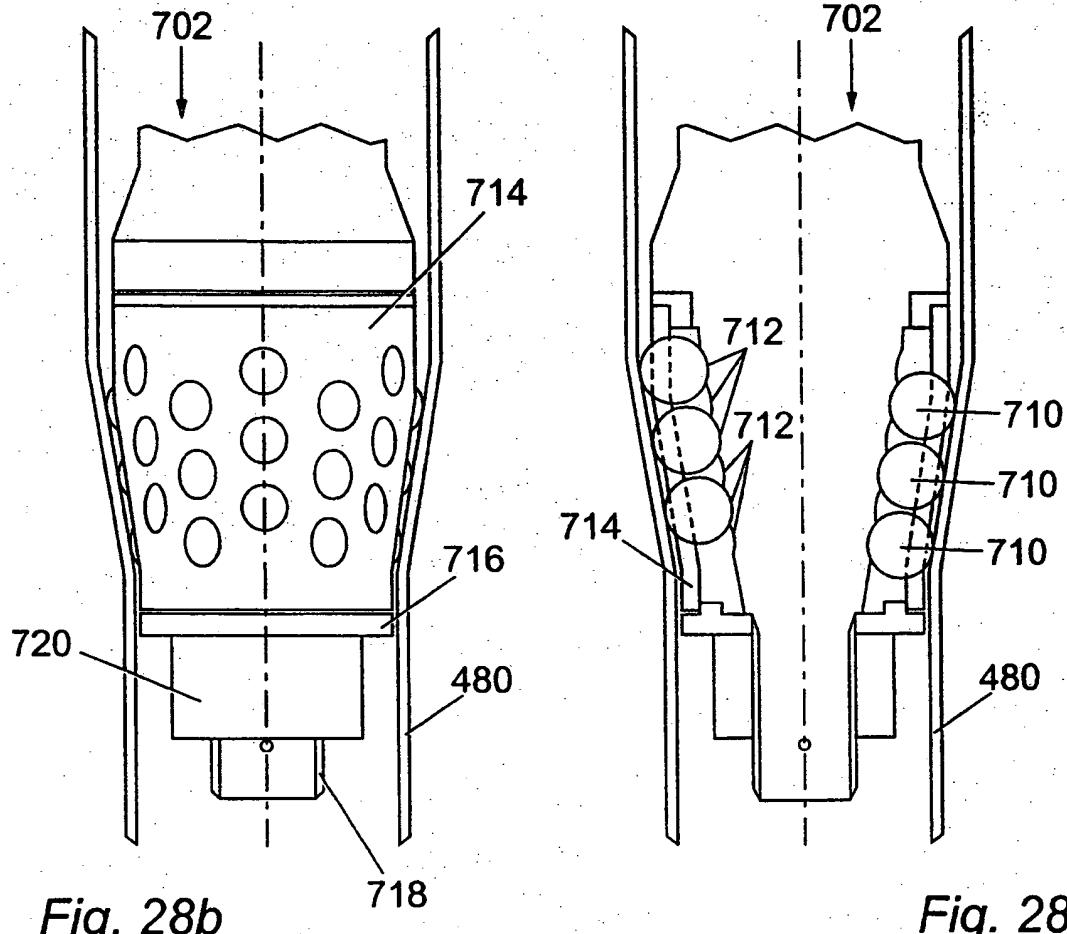


Fig. 27

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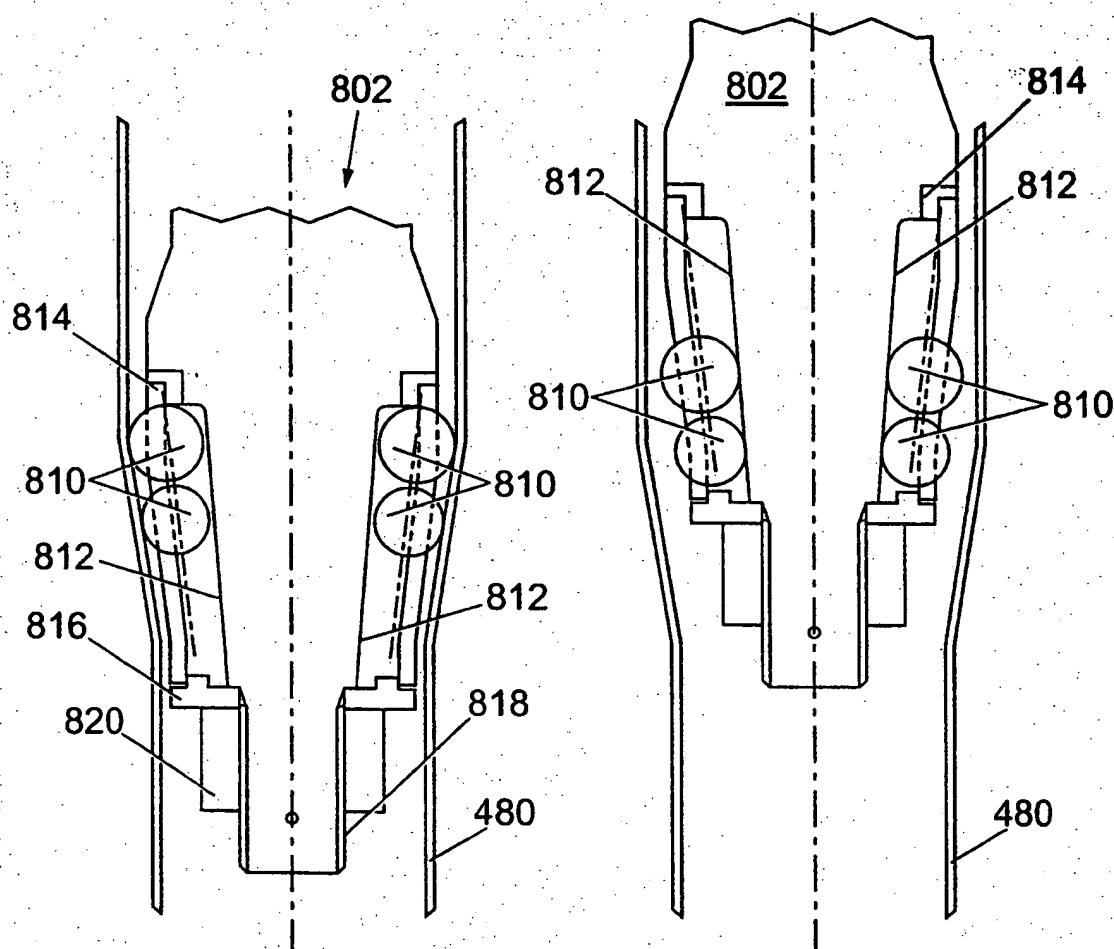


Fig. 29a

Fig. 29b

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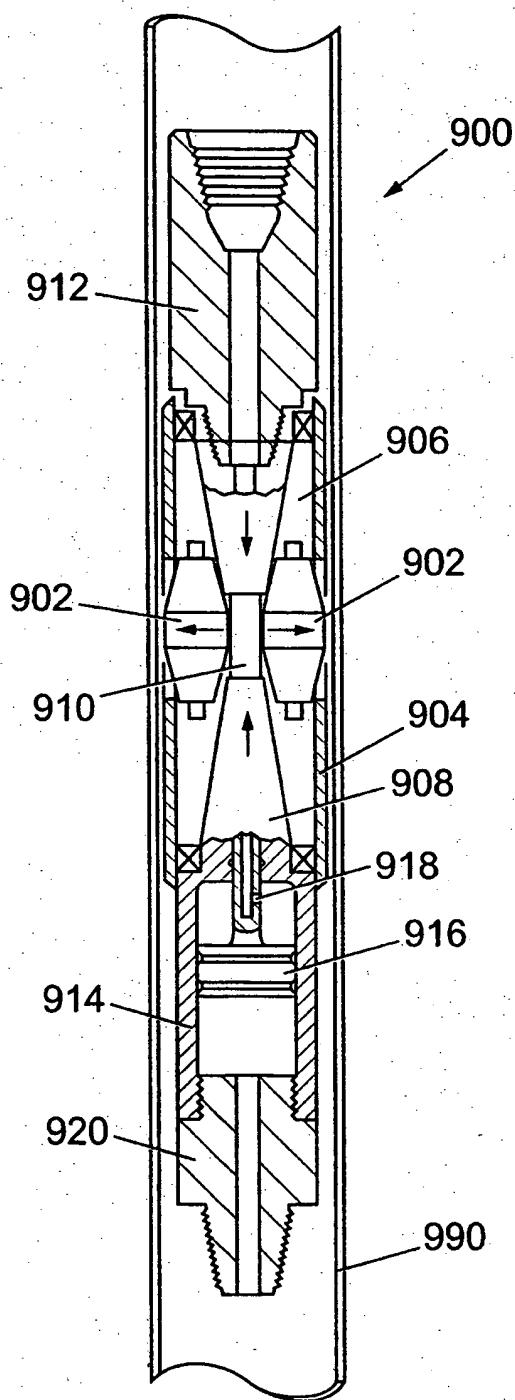


Fig. 30

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